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The Economics of Policies to Stabilize or Reduce Greenhouse Gas Emissions: the Case of CO_2

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Internal Paper

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* Head of Sector, Directorate-General for Economic and Financial Affairs. This paper is a revised and updated version of an internal paper prepared in October 1990. The author wishes to thank his colleagues at the Commission of the European Communities, notably Pierre Buigues, Jos Delbeke, Michael Emerson, Jan Scherp, Pierre Valette and David Wright as well as an anonymous referee for very helpful comments and suggestions. None of them bears any responsibility for the remaining short-comings and errors. In elaborating this paper, the author has largely benefited from a visit to the United States in the context of the International Visitors Progamme.

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THE ECONOMICS OF POLICIES TO STABILIZE OR REDUCE GREENHOUSE GAS EMISSIONS: THE CASE OF CO_2

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1. INTRODUCTION

In the past two years, the issue of policies to reduce greenhouse gas emissions has attracted an increasing amount of public attention, at the international level as well as within the Community. Last year, the members of working group N° 1 of the Intergovernmental Panel on Climate Change (IPCC) have concluded that they are certain that emissions resulting from human activities are substantially increasing and that these increases will enhance the greenhouse effect, resulting on average in an additional warming of the earth's surface. At the same time, the ongoing debate concerning the appropriate policy response is characterized by some degree of controversy. Moreover, economists have only recently started to address the issue. In order to assist policy-makers in the elaboration of a policy response to the risks of global climate change, the present paper reviews the economic issues that are involved and now have to be addressed.

The purpose of this paper, more precisely, is mainly twofold:

(i) first, to set out how, from an **economic** point of view, the design of policies directed at the "greenhouse issue" should preferably be approached **conceptually**;

(ii) second, to survey what is currently known **empirically** on the economic effects of different policies aimed at a reduction of greenhouse gas emissions and particularly CO_2 emissions.

Concerning the first aspect (economic concepts), the area covered by this paper touches upon a large number of policy areas beyond traditional economic policy analysis (notably energy, environment, transport, research and development, indirect taxes and development). This broadness was nevertheless felt necessary in order to arrive at a comprehensive and consistent approach concerning the greenhouse issue. As the ongoing policy debate sometimes appears to be characterized by a lack of understanding between natural scientists, environmentalists, economists and politicians, an attempt is made to bridge the gap in terms of analytical approach and language. Thus, this paper aims at encouraging a process of communication and mutual understanding.

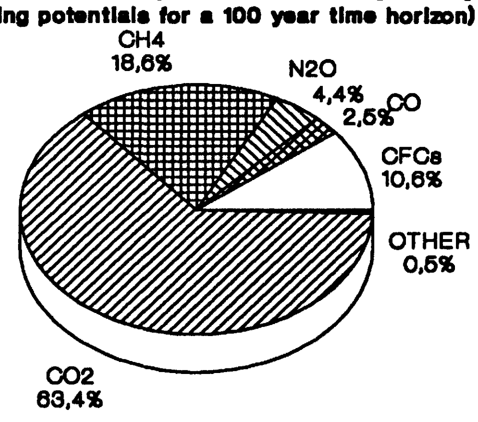
As to the second aspect (empirical analysis), two issues are of importance. First, throughout this paper the focus will be on the next two decades. Thus, the question of a possible large-scale (e.g. 60%) reduction of CO_2 emissions by the middle of the next century and the appropriate policies to reach such a target are beyond the scope of the present study. This is not to deny that the issue of global climate change is essentially a long-term question. However, the high degree of uncertainty associated with such a long time horizon, both in terms of the effects of higher atmospheric concentrations of greenhouse gases and in terms of the available technologies for response strategies would render such an analysis highly speculative. The design of the presently elaborated policy response has to reflect this fact. Second, it must be stressed that at present only very limited and sometimes even contradictory evidence is available. In particular, for many Community countries there appears to be relatively little information available at this stage, while comparatively more studies in the public domain have been elaborated for the United States. As time evolves, new information is likely to modify the picture. Nevertheless, the available information allows not only the priority areas for future research to be identified, but also some tentative conclusions to be drawn.

The structure of this paper is organized along the following lines:

- As a starting point, chapter 2 sets out the need for policy action by giving the factual background for the analysis in terms of both present as well as projected future greenhouse gas emissions and their expected effects.
- Chapter 3 then briefly describes the concepts and definitions underlying the economic approach to the greenhouse problem.
- This analytical framework is then applied in chapter 4 when addressing the issue of how economically optimal greenhouse policy targets should be defined.
- Chapter 5 addresses the question of the appropriate choice of policy instruments and the instrument setting required to reach the policy targets. It focuses on emissions related to the production and use of energy and analyses where and how these emissions could best be reduced.
- Chapter 6, in turn, looks at the somewhat different issue of deforestation and reforestation. What role can forests play in mitigating the greenhouse effect?
- Chapter 7 then addresses more specifically the international dimension (within the European Community and at the worldwide level) of both the definition of targets and the application of instruments. What are the main options and how can an agreement be reached?
- Chapter 8, finally, summarizes the main points of the study and tries to draw some tentative policy conclusions.

GRAPH 1: GLOBAL GREENHOUSE GAS EMISSIONS BY GAS (Shares in % of total)

(Calculated on a CO2 equivalent basis using IPCC global warming potentials for a 100 year time horizon)



SOURCE : EPA

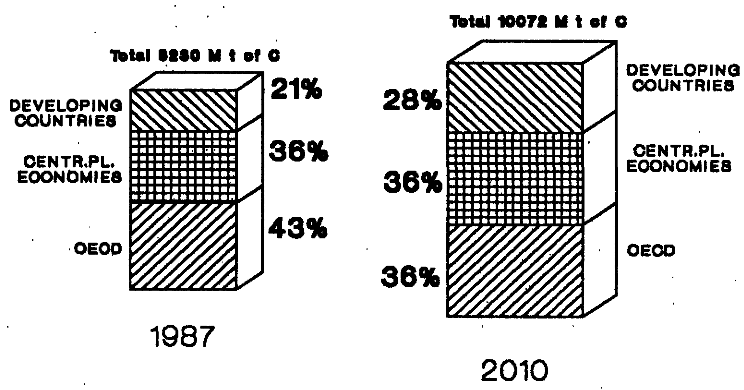
2. THE STARTING POINT: EMISSIONS AND EMISSION REDUCTION TARGETS[1]

2.1. Present emissions

Two aspects of the present emission of "greenhouse gases" are of particular importance in the context of this note:

- the share of different greenhouse gases in total emissions and
- the regional distribution of carbon dioxide emissions.

GRAPH 2: CO2 EMISSIONS FROM FOSSIL FUELS BY WORLD REGION 1987 and 2010



Source: DG XVII **Forecast for 2010: Scenario 1 ("conventional wisdom")**

First, in order to be able to calculate a meaningful share of individual different greenhouse gases in contributing to the overall "greenhouse effect", it is necessary to distinguish three dimensions of the problem:

1. the quantity of emissions for each gas;
2. the specific radiative forcing per molecule of the different gases;[2]
3. the lifetime of the different types of gases.

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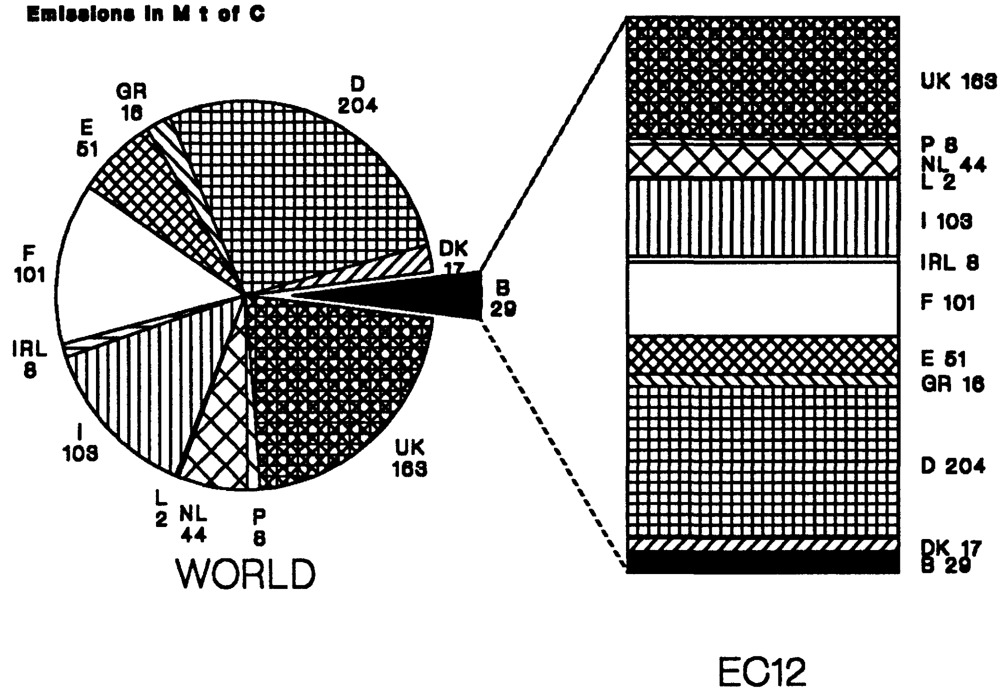
[1] For a good factual introduction to the "greenhouse" issue see, in particular, the reports established by the Inter-Governmental Panel for Climate Change (IPCC(1990a), IPCC(1990b), IPCC(1990c)) and appendix A of the US National Academy of Sciences Report (NATIONAL ACADEMY(1991)).

[2] "Radiative forcing" is a process which influences the earth's radiation balance, i.e. it changes the balance between the energy absorbed by the earth and the energy reflected by it in form of long-wave infrared radiation. According to the Inter-governmental Panel for Climate Change (IPCC), this radiative forcing potential of different greenhouse gases relative to that of carbon dioxide (CO_2) is: 21 times for methane, 290 times for nitrous oxide and between 3500 and 7300 times for CFCs (all calculated on a 100 year horizon). See IPCC(1990a).

GRAPH 3: REGIONAL DISTRIBUTION OF CO2 EMISSIONS FROM FOSSIL FUELS 1987



Source: Eurostat and DG XVII

Taking into account these different dimensions, it becomes clear that at present carbon dioxide (CO_2) contributes more than half to the overall (man-made) greenhouse effect, methane (CH_4) and chlorofluorocarbons (CFCs) contributing between 10-20%, respectively (see graph 1).[3]

Second, from the economic (policy) point of view (and contrary to the atmospheric point of view), it is important to know where the greenhouse gases are emitted in order to devise appropriate response policies. The origin has again two dimensions:

[3] In addition to the gases directly contributing to the greenhouse effect (CO_2, CH_4, N_2O, CFCs), there are some gases (e.g. CO and NO_X) that result from the combustion process, which are contributing indirectly to the greenhouse effect (e.g. by prolonging the atmospheric life-time of direct greenhouse gases or by encouraging the formation of tropospheric ozone). However, due to the complexity of the mechanisms involved, the relative contribution of such gases to the anthropogenic greenhouse effect is largely unknown (see RAPPORT DU GROUPE INTERMINISTERIEL SUR L'EFFET DE SERRE(1990) on this issue).

- the distribution by region: as is illustrated in graph 2 with respect to CO_2 emissions from fossil fuels, OECD countries are responsible for over 40%, slightly more than the (formerly) centrally planned countries and approximately twice as much as developing countries. The Community is currently estimated to contribute approximately 13% (graph 3);

- the distribution by economic activity: as can be seen in table 1, the production and use of energy is the source of almost half of the overall radiative forcing, followed by industry and forestry. Graph 4 illustrates, though, that the shares of the different activities and therefore also of the different greenhouse gases differs markedly between countries.

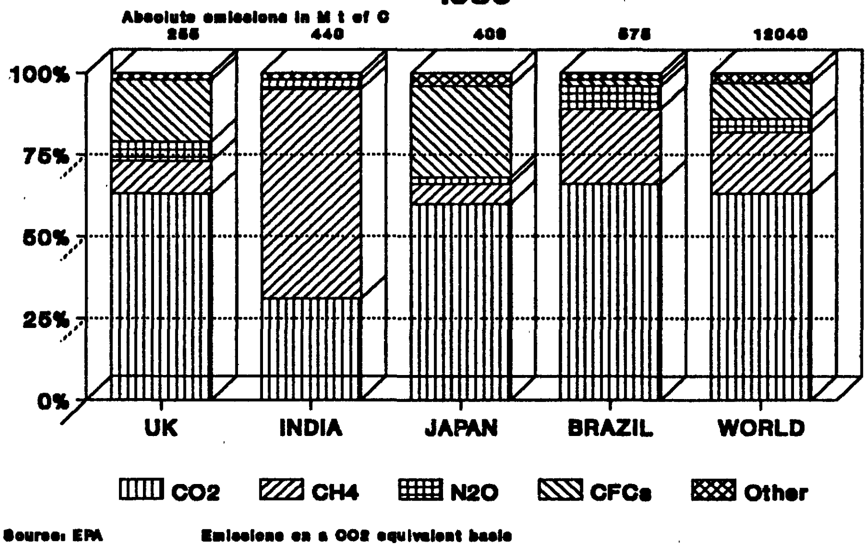
TABLE 1

ANTHROPOGENIC GREENHOUSE GAS SOURCES BY ECONOMIC ACTIVITY

Activity/ Sector	Gases	Sources	Relative contribution to radiative forcing in the 1980s (in %)
Energy production and use	CO_2	Combustion of fossil fuels for industrial, commercial, residential, transportation and other purposes	46 ± 8
	CH_4	Coal mining and venting of natural gas	
Industry	CFCs	Production and use in various industrial processes	24
Forestry	CO_2, CH_4, N_2O	Deforestation, biomass burning, including fuel wood and other changes in land use practices	18 ± 8
Agriculture	CH_4	Rice cultivation, livestock Use of nitrogeneous fertilisers	9 ± 4
Other sources	CO_2 CH_4	Cement manufacturing Land fills	3 ± 1

Source: *IPCC (1990c)*

GRAPH 4: GREENHOUSE GAS EMISSIONS BY GAS
Selected countries
1985



2.2. Forecast future emissions and their expected effects

Concerning future emission trends, projections show a continued, strong increase in greenhouse gas emissions from human activities under the assumption of unchanged policies ("business as usual"). Worldwide CO_2 emissions, for example, are projected to increase by roughly 60% in only 20 years. Developing countries will significantly increase their share in world emissions (see table 2 and graph 2).

For the European Community as well, carbon dioxide emissions are projected to increase noticeably (COMMISSION(1990a)). However, as can be seen in graph 5 and table 3, forecast emission trends vary significantly between countries. France and Germany, for example, may witness negligible increases, whereas for the new Southern Member States the increases may range from 30% (Spain) to nearly 90% (Portugal). The major part of the overall increase is expected to come from power generation and the transport sector (see graph 6).

Based on these emission forecasts - and taking into account the natural time lags - it is considered to be certain that atmospheric concentrations of greenhouse gases will be increasing substantially, thereby enhancing the greenhouse effect and resulting, on average, in an additional warming of the Earth's surface. On the basis of the present scientific knowledge, it is predicted that the global mean temperature could rise during the next century by about 0.3°C per decade (with an uncertainty range of 0.2°C to 0.5°C per decade), more than that seen over the past 10,000 years. IPCC members conclude that "this will result in a likely increase in global mean temperature of about 1°C above the present value by 2025 and 3°C before the end of the next century" (IPCC(1990a)).

TABLE 2

FORECAST WORLD CO_2 EMISSIONS UNTIL THE YEAR 2010

Country/ Region	Absolute CO_2 emissions 1987 (in M t of C)	Variations of CO_2 emissions 1987-2000 (in %)	Variations of CO_2 emissions 1987-2010 (in %)
EC12	746	19	24
USA	1395	23	37
Canada	122	31	51
Japan	260	23	32
Rest of OECD	180	32	56
Total OECD	2703	23	35
CPE	2228	36	64
LDC	1299	57	114
WORLD	6230	34	62

Source: *Commission (1989b)*
"Conventional wisdom"scenario

As a consequence, the global mean sea level is predicted to rise by about 20cm by the year 2030 and by 65cm by the end of the next century. All these projections are not only subject to a high degree of uncertainty, but also hide a considerable - although not yet fully known - degree of regional variation. However, it is important to stress two points:

1. Due to the as yet unknown net effect of different natural feed-back mechanisms, the uncertainty concerning the climatic impacts of a multiplication of the pre-industrialized atmospheric concentration levels of greenhouse gases can play in both directions: while it is possible that temperatures would rise less, it is also possible that without policy changes the rise would be significantly higher and faster, exceeding the adaptability of the natural fauna and flora and leading to catastrophic impacts on our eco-system (for a discussion on the likely impacts from global warming see IPCC(1990b); for three regional assessments of the socio-economic impact see PARRY/MAGALHÃES/NINH(1991)).

TABLE 3

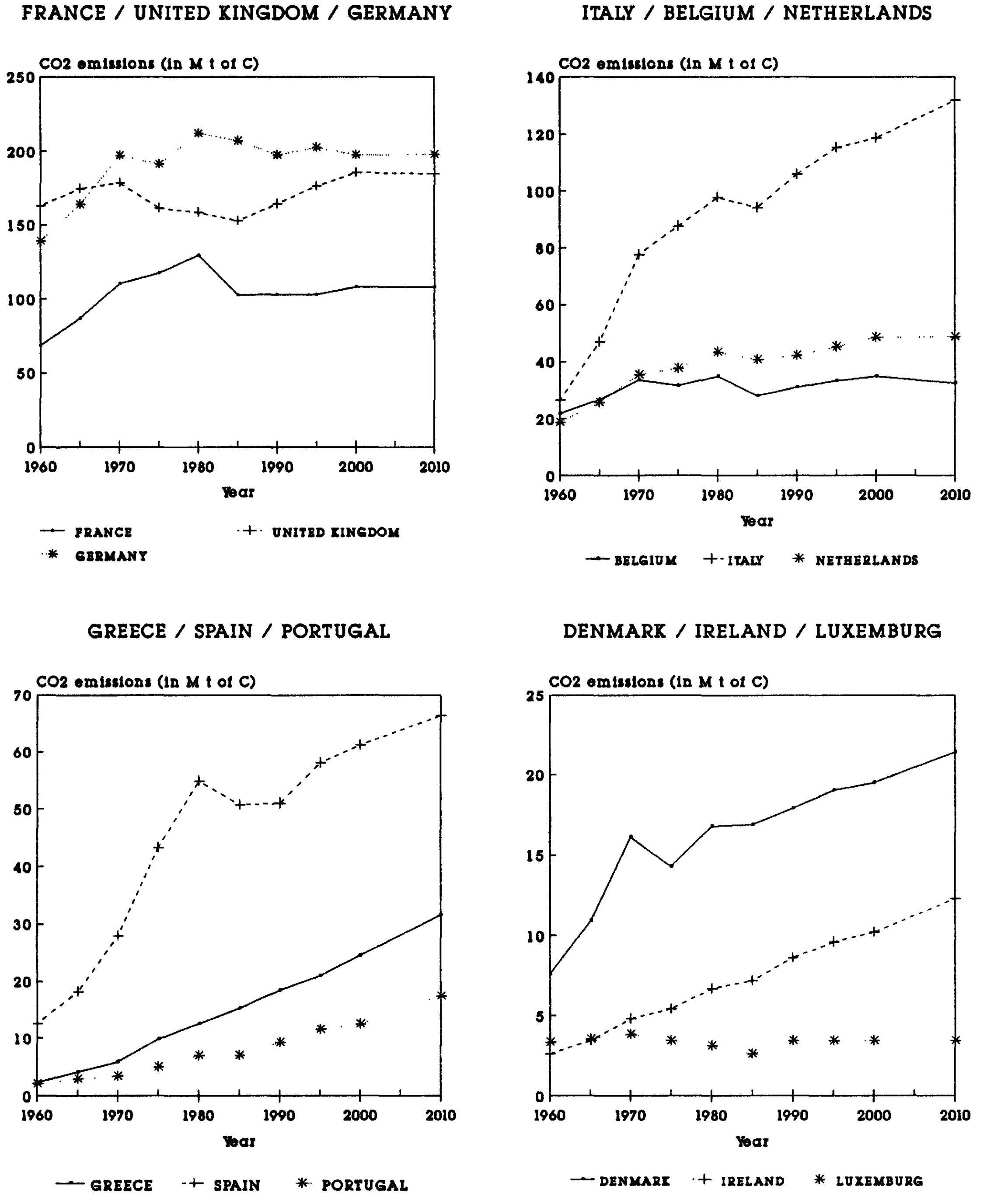
FORECAST CO_2 EMISSIONS UNTIL THE YEAR 2010 IN THE EC

	Absolute CO_2 emissions 1990 (in M t of C)	Variations of CO_2 emissions 1990-2000 (in %)	1990-2010
EC12	753	9	14
Belgium	31	12	4
Denmark	18	9	20
Germany	198	0	0
Spain	51	20	30
France	103	5	5
Greece	18	33	72
Ireland	9	19	43
Italy	106	12	24
Luxembourg	3	0	-3
Netherlands	42	14	15
Portugal	9	33	86
United Kingdom	165	13	12

Source: *Commission (1990a)*
Working Document N°4
Balance Sheets of Pollutants SO_2, NO_x, CO_2
"Conventional wisdom" scenario

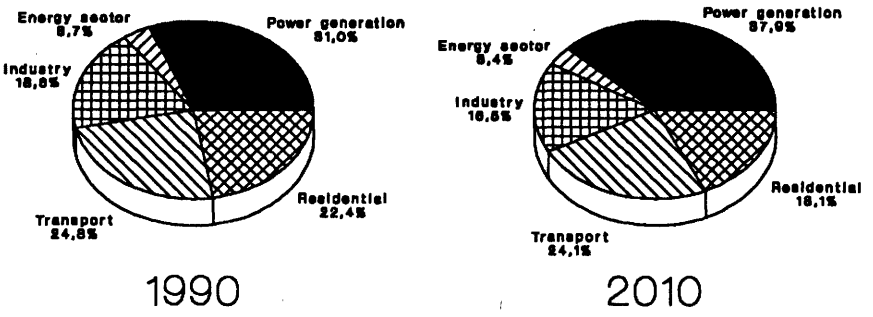
2. Most climate studies to date apply a technique economists call "comparative-static". In fact, the analysis only compares two (assumed equilibrium) situations, namely today's situation and one where the atmospheric concentrations of greenhouse gases are twice today's level. Nothing (or at least very little) is yet known on the transition path from one situation to another (would more frequent and more severe storms occur? How would changes in cloud formation influence the climate? Would the present ocean currents that shape regional climate patterns change? Would temperate forests, already weakened by acid rain, survive? Would regional droughts lead to massive migration? etc.). It is important to stress this point, as the problem of global climate change most of all is one of transition.

GRAPH 5: CO2 EMISSION TRENDS IN THE EC - 1960 TO 2010



Sources: 1960 to 1985: Eurostat; 1990 to 2010: DG XVII (forecasts)

GRAPH 6: FORECAST CO2 EMISSIONS IN THE EC BY SECTOR (as % of total)
Scenario 1: Conventional wisdom



Source: DG XVII

2.3. Announced emission limitation targets

Against this background, several countries have announced their commitment to stabilize or reduce the emission of greenhouse gases in order to slow down global warming. In the Community, several Member States have either adopted emission limitation targets (phasing-out of CFCs and stabilisation/reduction of CO_2) or have pronounced themselves in favour of such orientations. However, these objectives differ in many respects between countries (degree of commitment, conditionality, reference year, target year etc.) and, moreover, cover only a limited number of Member States.

In addition to these national targets, a joint Council of the European Community's Energy and Environment Ministers declared, on October 29, 1990, that the European Community and Member States are willing to take actions aimed at stabilizing total CO_2 emissions by the year 2000 at 1990's level in the Community as a whole. The Council also noted that the Commission will present in due time a proposal for establishing Community emission reduction targets separately for CO_2 and other greenhouse gases, and including possible strategic options aimed at progressive reductions at the horizon 2005 and 2010.

3. ECONOMIC CONSIDERATIONS CONCERNING THE POLICY DESIGN: CONCEPTS AND DEFINITIONS

3.1. The overall objective

Before starting the discussion of the economic aspects of "greenhouse policies" it is necessary to briefly set out the general objective of economic policy and indeed of any economic analysis in general. To put it in the most general terms, an economist's objective is to maximise - subject to given constraints - overall human welfare on the basis of a given set of citizens' individual preferences. Economic policy objectives like price stability, full employment, economic growth etc. are only targets derived from this basic objective.

Given that people's preferences are seen as being determined exogenously, an economist's aim is in principle not to influence these preferences. Instead, the aim is to reach the highest possible level of sustainable social welfare. This implies most importantly that economic analysis focuses on the question of how given targets (including, for example, the preservation of specific environmental properties or the well-being of future generations) can be reached most efficiently, i.e. - in economic terms - in the most cost-effective way. It is this search for the most efficient set of policies addressing the greenhouse issue that is the basic objective of this study.

3.2. The notion of costs and benefits

The expression of "cost-effectiveness" requires a brief discussion in order to avoid some of the misconceptions sometimes encountered in public discussion. As has been set out in the previous paragraph, the overall policy aim is to maximize social welfare. True "costs" of policies would therefore refer to <u>reductions in social welfare</u>. There is also the notion of economic opportunity cost. Opportunity costs arise from the fact that a certain amount of resources can only be used once. The opportunity costs of a certain investment, for example, consist of the foregone alternative use of the resources (e.g. for consumption). In the case of perfect markets without externalities, opportunity costs equal <u>expenditures</u> at market prices.

In preparation for the subsequent discussion the following additional distinctions are of particular importance:

- <u>private versus social costs</u>: private costs are those costs faced by the individual economic agent. These costs may differ from the costs to society (so-called social costs) to the extent that prices do not fully reflect all the costs (i.e. also the environmental costs) of a certain activity or product to society. To give an example, pollution does usually not imply any costs for the polluter, while the damage to the environment caused by the pollution constitutes a cost to society. Measures to reduce the pollution unambiguously raise the costs for the private economic agent. However, provided the costs of the pollution abatement measures are lower than the damage to the environment, society as a whole would be better off by undertaking such measures. As these "externalities" are at the heart of the issue of pollution, they will be discussed in more detail further below. It is important to retain for the subsequent discussions, however, that private (expenditure-based) cost estimates may be a poor measure for social cost (for an empirical demonstration see HAZILLA/KOPP(1990)).

- <u>marginal versus average costs</u>: when discussing cost figures it is important to distinguish marginal from average costs. As the costs per unit produced or per emission abated normally vary with the amount produced or abated, average costs differ from marginal costs. As the costs of reducing greenhouse gas emissions usually increase with the amount of reduction, the marginal costs of reducing emissions by an additional unit normally exceed the average costs of the total emission reduction.

- adjustment costs: in addition to the resource costs of efficiently producing a given output as traditionally focused upon by economic theory, there may also be adjustment costs arising when the factor input combination is changed.[4] These adjustment costs of course also represent real resource or opportunity costs. Thus, even when a change from a highly polluting production process to a less polluting process implies welfare gains to society, the size of these gains may be reduced by the occurrence of costs of adjustment. It is therefore important to take into account adjustment costs when evaluating different policy options.

A final definition is required before proceeding with the analysis. In this study, the term 'benefit' is used in the sense of 'negative social cost'.

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[4] BOERO/CLARKE/WINTERS(1991) use the terms "continuing costs" and "transitional costs" for describing this important distinction.

4. ON THE DEFINITION OF POLICY TARGETS

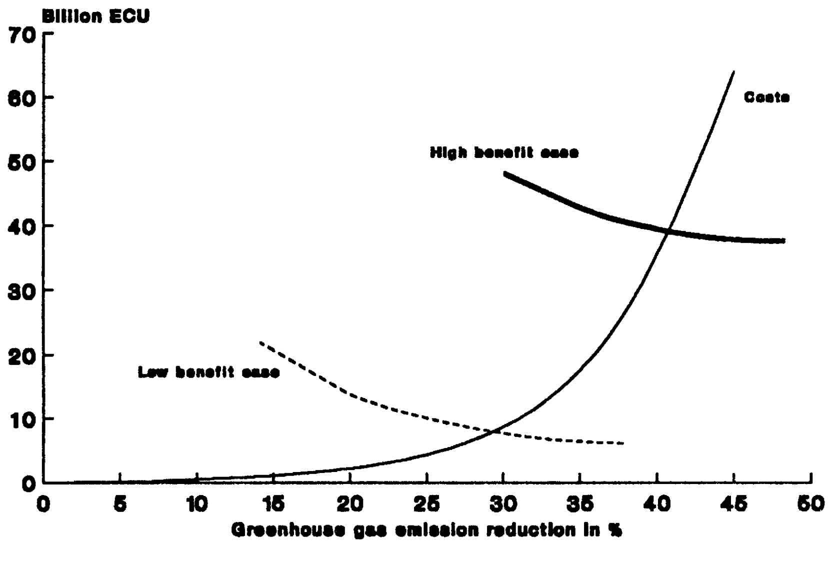
4.1. The search for the optimum

4.1.1. The cost-benefit approach

Does the increase in atmospheric concentrations require a change in policies? What policy targets should be set? The economic approach to answering these questions is to compare the cost of action - preventive (e.g. investments to reduce greenhouse gas emissions) or adaptive (e.g. coastal protection measures) - with the benefit arising from action (e.g. reduced damage due to floods). It is interesting to note that the Community is even legally obliged to do so: Article 130r of the Treaty specifies that "in preparing its action relating to the environment, the Community shall take account of (...) the potential benefits and costs of action or lack of action". While such a comparison is preferably done in quantitative terms, it is also possible to do it on a merely judgemental basis in cases where quantification is impossible.

The advantage of adopting a cost-benefit view can be illustrated by reference to the issue of greenhouse gas emission targets. As has been calculated by the IPCC Working Group N°1, stabilizing atmospheric concentrations of long-lived greenhouse gases at today's level would require immediate reductions in emissions from human activities of over 60%. Reversing the rise in concentrations due to past man-made emissions would therefore require even larger emission reductions. However, only few propose such drastic action and some might even argue that the rise in average temperatures observed over the past hundred years does not seem to have harmed our lives. Thus, what is the economically desirable amount of emission reduction?

GRAPH 7: AGGREGATE EMISSION REDUCTION COST AND BENEFIT CURVES
(Purely illustrative)



Assume that the marginal costs of reducing greenhouse gas emissions tend to increase with the amount of reduction (see graph 7). Such a marginal cost curve alone is clearly insufficient to determine the desirable degree of emission reduction. It shows that, ceteris paribus, an emission reduction by 45% would be many times more expensive than a reduction by 25% percent, but it does not show whether such a reduction would be worthwhile or not. In fact, in order to answer this question, knowledge on the benefits from the different amounts of emission reduction is required. The optimal amount of emission reduction therefore depends on the shape of the marginal benefit function (e.g. high versus low benefit case in graph 7). This illustrates the need for thinking about costs and benefits when defining policy targets.

4.1.2. A comprehensive approach covering all the dimensions of the problem

As has been set out above, from the economic point of view, the general objective is to maximize the net benefits (welfare gains) from greenhouse policies. The question then is of how such a set of optimal policies can be identified analytically.

From the theoretical point of view, the overall cost minimum (or net benefit maximum) of such a set of policies can only be reached in the context of a comprehensive approach covering all options and dimensions of the problem. Incidentally, this has also been highlighted by the IPCC's Response Strategies Working Group (see IPCC(1990c)).

From the methodological point of view, such a truly comprehensive approach would require that:

- all types of greenhouse gases are taken into account.[5] As the economic costs of reducing emissions differ between the different greenhouse gases, it is sensible to identify emissions of those gases that are cheapest to reduce. Limiting oneself to only one type of gas is likely to increase the overall cost of reaching a given target in terms of radiative forcing.

- all sectors of economic activity and all available technologies are considered. Given the fact that the costs of emission reductions vary across sectors of economic activity and technologies, focusing only on a subset cannot lead to the cost-minimum.

- all regions are covered. As greenhouse gas emissions themselves have no (or only very limited) local, regional or national effects, any isolated national policy of emission reduction is potentially ineffective and therefore also economically inefficient as it does not attain the objective of reducing the greenhouse effect. In fact, it even cannot be ruled out that the relocation of CO_2-intensive production sites from countries with strict greenhouse gas reduction policies to countries without restrictions and with low energy efficiency technologies might increase worldwide emissions.

- both greenhouse gas "sinks" and sources are integrated into the analysis. Since from the climatic point of view it is not **emissions** as such that cause the greenhouse effect, but only **atmospheric concentrations** (i.e. emission minus absorption) of greenhouse gases, any policy only focusing on emissions is unlikely to be efficient and may indeed be totally ineffective. The more greenhouse gas emissions (e.g. CO_2) can be absorbed by greenhouse gas sinks (i.e. the less atmospheric concentrations increase), the less emissions need to be reduced to reach a given target in terms of mitigating global warming.

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[5] For an attempt to follow such an approach by using the concept of "Global Warming Potential (GWP)" for aggregating different greenhouse gases, see CRISTOFARO(1990) or MORGENSTERN(1991). See also ECKAUS(1990) for an economist's criticism of using a GWP index as a policy guide and his proposal to use the concept of "Emissions Opportunity Cost (EOC)" instead.

- emission abatement measures, adaptation measures and inaction have to be considered. There is no a priori reason for assuming that emissions of greenhouse gases necessarily have to be avoided. In fact, at least in the long-run, a number of alternatives are available (see graph 8) and from the purely economic point of view the least costly one(s) should be used.

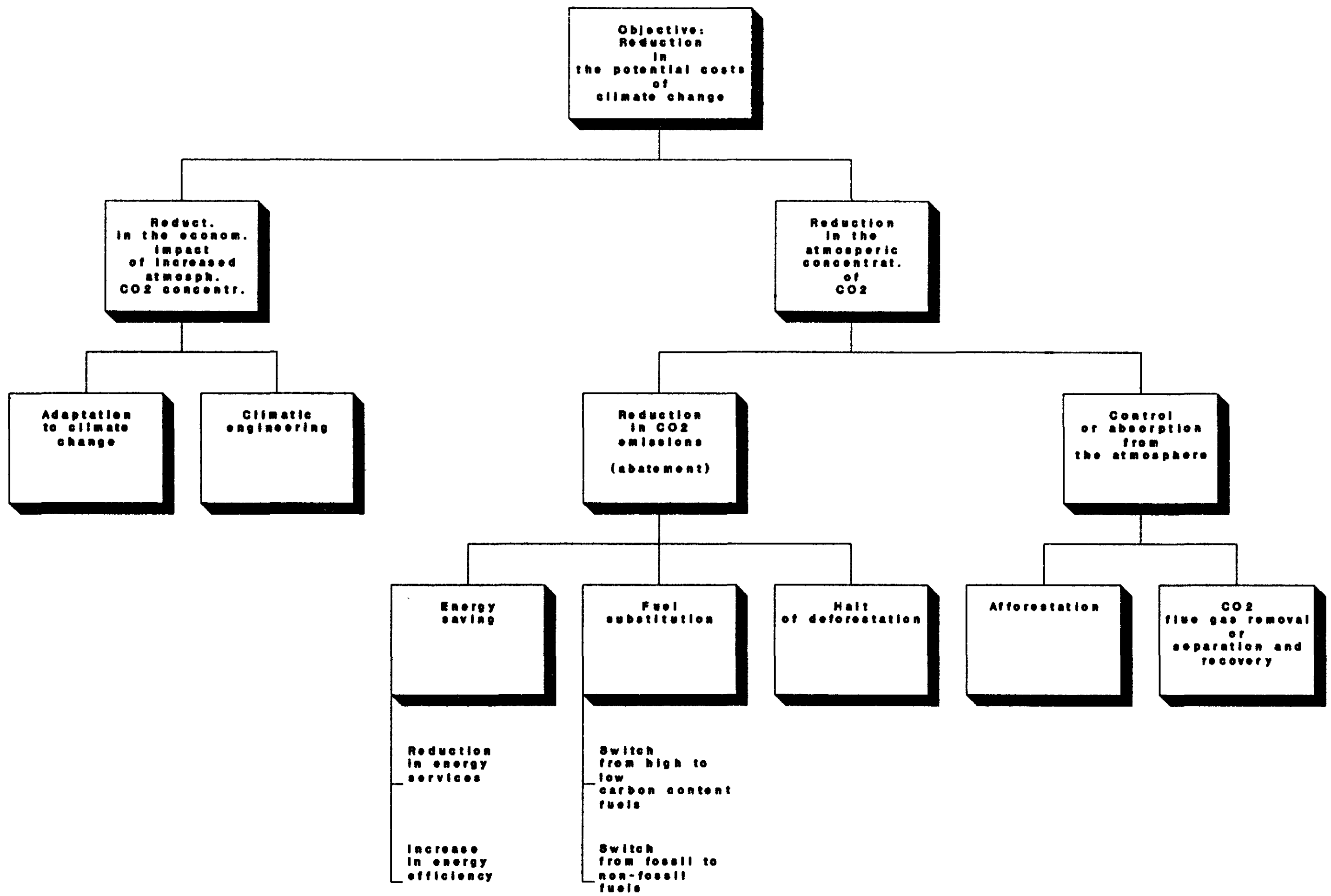
  Thus, on the emission side for example, it is either possible to avoid burning fossil fuels (therefore not generating emissions) or to abate emissions by using so-called end-of-pipe technologies for flue-gas removal (therefore not releasing them into the atmosphere) to prevent an increase in the atmospheric concentration of greenhouse gases. Alternatively, one could also envisage a process of CO_2 separation and recovery by converting coal into synthetic gas (see e.g. CHANGE(1991)). While at present no such technologies appear to exist, ongoing work suggests that this option could well be available in the future, at least for stationary sources (see e.g. FINANCIAL TIMES(1990)). However, at present the problems of such a procedure seem to be enormous (high technical and financial effort, reduced efficiency of energy conversion, unsolved question of long-term storage).

  On the effects side, one option consists of adapting - either now or later - to the effects of global warming. After all, the climate has never been "constant". As a matter of fact, some authors emphasize that only a very small amount of industrialized countries' economic activity is directly weather dependent (mainly agriculture). Moreover, there is no consensus as to whether higher atmospheric CO_2 concentrations would reduce agricultural productivity or not. It is therefore argued that it might be economically preferable to adapt to global warming by undertaking measures to protect coastal zones (for an economic assessment see e.g. RIJSBERMAN(1991)), to move human and economic activities to other areas etc..

  Theoretically, a second option exists on the effects side, namely to attempt to mitigate the effects of increased greenhouse gas concentrations by means of curative action, for example through measures to increase the earth's surface reflection or through "climatic engineering" (see e.g. NORDHAUS(1990c)). However, in view of the almost complete lack of knowledge and the high stakes involved, the latter approach represents a high-risk option and will not be considered as a serious option in this paper.

Admittedly, the comprehensive approach described above is too complex to be immediately and fully implemented empirically. Often the knowledge required for such an analysis is unlikely to be readily available. In addition, there are political and geopolitical realities and constraints to be considered. However, it is crucial to adopt a policy approach as broad as possible. The reason for this is fairly straightforward: The broader the approach, the cheaper it is to reach a given overall policy target, or, in mathematical terms, a limited approach at best only allows one to attain a local cost minimum. The overall cost minimum can only be attained if all options are evaluated and the cheapest are chosen. Thus, to put it differently, economic theory suggests that the broader the approach, the more ambitious the environmental policy targets that can be met for a given amount of money. A comprehensive approach therefore should not be interpreted as being in conflict with a precautionary philosophy.

GRAPH 8: RESPONSE OPTIONS TO REDUCE THE POTENT.COSTS OF CO2 RELATED CLIM. CHANGE



4.1.3. Conceptual and empirical complications

Although from a theoretical point of view the cost-benefit approach to the evaluation and design of greenhouse gas emission reduction policies is the appropriate way to deal with the issue from the economic perspective, the implementation of this approach is hampered by numerous conceptual as well as empirical problems. Although these complications by no means only arise in the case of global warming, they nevertheless have to be addressed in this context.

First, there is the problem of uncertainty or imperfect information. This uncertainty effectively relates to several dimensions of the problem:

- the amount of future emissions (uncertainty concerning economic and population growth, behavioural changes, technological developments etc.);

- the increase in future atmospheric concentrations (e.g. uncertainty concerning the functioning of carbon sinks);

- the effects of global warming on the eco-system;

- the effects of changes in the eco-system on the economic system;

- the effects of the application of policy instruments to reduce emissions (i.e. uncertainty concerning the effectiveness and/or the costs of different measures).

From the economic point of view, the uncertainty with respect to the economic impacts of global warming is particularly important as such effects have to be quantified in order to perform a cost-benefit evaluation. Contrary to a situation of risk, however, uncertainty relates to contexts in which probabilities are unknown and therefore where mathematical approaches based on expected values are not applicable.

It is important to stress, however, that the existence of uncertainty does not imply that "no action" is the optimal strategy from the economic point of view. All it requires is that the decision analysis takes into account the existence of uncertainty. A priori, two ways exist to deal with the existence of uncertainty in this context: either the available resources are focused on reducing uncertainty (achieved by financing more scientific research), or they are spent on limiting the likelihood of negative outcomes (achieved, for example, by reducing emissions).

In this context, it is also necessary to address the issue of risk neutrality versus risk aversion. The available evidence suggests (see BARBIER/PEARCE(1989) for details) that society is likely to be willing to pay a certain sum only in order to avoid the future risks of climate change. This risk-aversion premium (the so-called option value) has to be added to the expected welfare costs of taking action when undertaking a cost-benefit comparison.

Second, there are a number of valuation problems, including the issue of irreversibility and the treatment of coincidental benefits.

- When undertaking a (quantitative) cost-benefit analysis, an important difficulty arises from the fact that monetary values are required for comparing the costs with the benefits. Often, however, environmental goods and services are not marketed. (These market externalities are exactly the cause of the environmental problem in the first place.) Thus, there are no market prices that can be used for the economic valuation of these environmental values. In order to overcome this problem, a valuation of these environmental values. In order to overcome this problem, a number of monetization methods have been developed which at least allow the calculation of proxies, notably based on the willingness to pay principle (e.g. the hedonic price approach, contingent valuation or the travel cost approach; for details see PEARCE et al. (1989)).

- As regards irreversibility, the question of how to value, for example, extinct species (flora and fauna) is of significant importance. Moreover, the existence of lags of several decades between the emission of greenhouse gases and the consequent climate warming aggravates the irreversibility problem: by the time climatic effects are known 'with certainty', it is probably too late to act.

- The same is true for the integration of coincidental or joint benefits. This is particularly important for the evaluation of policies to reduce CO_2 emissions as any reduction in fossil fuel consumption due to energy efficiency gains at the same time also reduces emissions of other gases, particularly SO_2, CO and NO_x. Neglecting such joint benefits is likely to lead to an amount of emission reduction that lies below the social optimum.[6]

Third, there is the issue of <u>discount rates</u> and <u>intergenerational justice</u>. The problem of discount rates arises from the fact that the costs and benefits of measures to reduce greenhouse gas emissions occur at different periods in time. In the case of global warming, for example, the cost of emission reduction investments arise in the present while the benefits of the emission reduction will only arise several decades into the future. In order to compare the costs with the benefits, it is necessary to discount future monetary flows to present values. The application of a discount rate is usually justified by reference to individual economic agents' time preferences and the marginal productivity of capital (see e.g. MARKANDYA/PEARCE (1988)): it is assumed that individuals generally prefer consumption now to consumption later. Individuals only forego present consumption (i.e. they save/invest), if the rate of return on these savings/investments is at least as high as the rate of individual time preference. Analogously, society as a whole is considered to have an aggregate time preference. Capital, on the other hand, will only be invested (instead of being consumed), if the productive use is expected to yield a higher product in the future compared to what has to be invested today.

The question is then of which discount rate to use and whether differentiated discount rates should be used as a policy instrument. A high discount rate has the effect of leading to small present values for even catastrophic economic losses. To give an example, if a discount rate of 10% per annum were used, any single ECU spent today on emission reduction investments has to reduce future damage in the year 2090 by at least ECU 13780 in order to be "profitable".

This raises the question of whether it is ethically permissible to discount the damage brought about on future generations in this way. The answer to this question depends mainly on whether it is possible to compensate future generations as well as on the ethical standards applied (for details see PEARCE et al.(1989) and D'ARGE et al. (1982)). If one adopts a narrow notion of 'sustainable development' as a basis for the policy evaluation, future generations have to be guaranteed to be endowed with a natural capital stock at least as high as the present stock in order to be able to satisfy their needs. (Note that the Treaty of Rome as amended by the Single European Act requires Community action "to preserve, protect and improve the quality of the environment" (Art. 130r).) On the other hand, using a lower discount rate for public investments in mitigating global warming than

[6] The coincidental benefits from planting trees in terms of reduced soil erosion and higher ground water level are another example in this context.

for other public investments (e.g. education or infrastructure) is difficult to justify economically (see e.g. NORDHAUS(1990c)).

In view of the above discussion it is hardly surprising that, up to now, only very few attempts have been made to apply the general cost-benefit approach to the issue of greenhouse policy. The most comprehensive attempt so far has been made by NORDHAUS, who investigated - primarily on the basis of data for the United States - the design of an (economically) optimal greenhouse policy (for details, see the attached box). The main conclusion of the Nordhaus analysis is that, in a medium damage scenario, cost-benefit analysis would suggest an economically efficient amount of total greenhouse gas emission reduction of the order of 11% (see NORDHAUS(1991a)). However, other authors arrive at substantially higher optimal emission reduction levels, either because they base their analysis on higher climate change damage (e.g. CLINE(1990b)), or because they arrive at both higher damage and lower costs of emission abatement than Nordhaus (e.g. AYRES/WALTER(1990)).

In any event, there appears to be broad agreement on the fact that present knowledge about the likely damage from global climate change is extremely sketchy and that, therefore, any cost-benefit analysis has to be interpreted with great caution. What is important for the proper utilisation of such analyses, however, is the distinction between the (likely) damage from global warming and the (potential) benefits from greenhouse gas emission reduction policies. Both are not identical because, on the one hand, not all damages will be avoided by emission limitation policies (unless atmospheric concentrations are stabilized), and, on the other hand, the benefits of greenhouse gas emission limitation policies are larger than the benefits from only slowing down climate change (coincidental benefits).

BOX: The Nordhaus Analysis

By estimating aggregate cost and benefit functions, William NORDHAUS(1989, 1991a, 1991b) has attempted to identify the point at which the marginal cost of an additional reduction in greenhouse gases just balances the marginal damage from the additional climate change from the higher concentration of greenhouse gases. The main **tentative conclusions** of this empirical evaluation were that:

(a) about 10-20% of greenhouse gas emissions can be reduced at low cost. Above that level, the marginal costs of abatement rise sharply;

(b) on the basis of a middle damage function implying a shadow price of $ 7.3 per ton of CO_2 equivalent (carbon weight), the optimal policy would consist of reducing total emissions of greenhouse gases by 11%. On the basis of a high damage function (shadow price of $ 65.9 per ton of carbon), it would be optimal to reduce emissions by slightly over 30% (see graph B1);

(c) most of the greenhouse emission reduction would come in both cases from a virtually complete phase-out of CFCs, while CO_2 emissions would only be reduced by 2% and 20%, respectively. This illustrates the potential economic gains from using a framework integrating all, or at least several, greenhouse gases;

(d) concerning the instruments of reducing emissions, a global carbon tax is economically superior to a US gasoline tax, while the option of reforestation is never economically justified.

Although the Nordhaus analysis is a very valuable contribution to the discussion on greenhouse gas policies, it is subject to a number of serious **short-comings and limitations** (which, however, are not limited to only this specific analysis):

1. First, it can be questioned whether at present there is sufficient scientific knowledge to quantify the damage function. This concerns, first of all, regional climate changes. In fact, a reliable quantification of the likely damages would require much more information than the presently available estimates of average temperature and sea level increases. However, the present generation of climate models (General Circulation Models) do not yet provide the regional detail necessary for a sound calculation of the economic impacts (see also COOPER(1991) on this issue).

2. Second, the comparatively low damage figures partly arise from the fact that only agriculture and forestry are considered to be significantly climate dependent in a comparative-static analysis comparing present and future average temperatures and precipitation levels. (In fact, due to possible increases in crop yields in response to a "CO_2 fertilisation effect" agriculture could, according to some researchers, even benefit in such an analysis.) However, such an analysis assumes a smooth transition from one "equilibrium" to another and therefore neglects any costs of transition. Should the frequency and intensity of certain weather events, for example (tropical) storms, increase during the transition process, other sectors of the economy would potentially be directly affected as well. However, at present, scientific knowledge on the impacts of the global warming process on storm patterns is still in its infancy.

BOX: (continued)

3. Third, the Nordhaus analysis only considers the benefits from slowing global warming. However, greenhouse gas emission reductions will at the same time lead to reductions in stratospheric ozone depletion (CFCs), acid rain (SO_2), local air pollution etc.. Thus, taking into account these coincidental benefits (see above) the optimal emission reduction is likely to be larger. While some authors (e.g. GLOMSRØD et al.(1990)) come to the conclusion that the additional benefits (in terms of improved health conditions etc.) of a reduction in fossil fuel use could amount to roughly 2/3 of the calculated GDP loss, others (e.g. ECONOMIC SURVEY(1991)) suggest that the benefits in terms of reduced traffic-related external costs as well as of reduced negative health effects due to NO_x emissions could even almost be of the same order as the GDP losses. This leads some observers (e.g. BARRETT(1990b)) to suspect that the economic benefits from the (automatic) reduction in SO_2 emissions may even exceed the benefits from the reduction in CO_2 emissions.

4. Fourth, to some extent, the restriction of the analysis to an assumed doubling of atmospheric concentrations of greenhouse gases by the end of the next century (and the corresponding degree of warming) cuts off the analysis at a somewhat arbitrary point in time. As has been argued by William CLINE (1990), considering a longer time period could imply significantly higher temperature rises and possibly geometrically (instead of linearly) rising economic effects as a function of the absolute warming level.

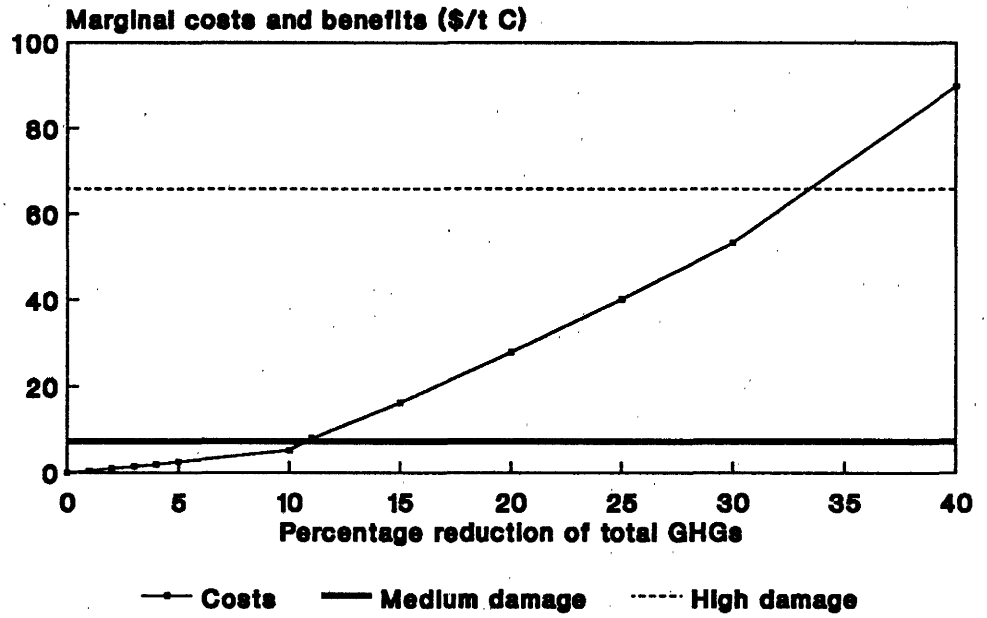
5. Fifth, Nordhaus only looks at damage from global warming to the extent to which they are reflected in our traditional system of national accounts. Thus, damage affecting the ecosystem, but not valued by the market, (for example, losses of bio-diversity, wet and dry lands, coral reefs etc.), are not captured. There is broad agreement, however, that such damage is likely to be significant (see e.g. INTERAGENCY TASK FORCE(1990)).

6. Sixth, as the discussion further below in section 5.3 will show, there appear to be a number of possibilities for reducing greenhouse gas emissions (in particular CO_2 emissions) by undertaking energy conservation measures which would result in an economic gain rather than an economic loss. This potential has not been taken into account in the Nordhaus analysis, as Nordhaus assumes perfect markets and thereby neglects any inefficiencies in the use of energy.

Although the above observations by no means invalidate the analysis undertaken by William Nordhaus (and, indeed, several of the points are explicitly acknowledged by the author), they nevertheless tend to indicate that there is likely to be a certain bias in the analysis. This bias can be expected to imply that the "optimal" emission abatement level, as derived from cost-benefit analysis, would be higher if the above limitations were removed.

BOX: (continued)

GRAPH B1: GREENHOUSE GAS REDUCTION COSTS AND BENEFITS



Source: NORDHAUS (1991a)

4.2. Simplifying the analysis

It has become clear from the discussion in the previous section that the application of a comprehensive policy approach is associated with formidable -though not necessarily insoluble- difficulties. This is not invalidating the approach. On the contrary, as the IPCC's Response Strategies Working Group states: "It is imperative that further work on the cost and benefit implications of response strategies be undertaken" (see IPCC(1990c)). However, this is a medium- to long-term task. In the short-term, ways have to be found to simplify the task.

4.2.1. Fixing quantities: the absorption approach

One of the possibilities of addressing the problem of defining greenhouse gas limitation policies is to define atmospheric concentration targets and derive emission targets from these concentrations. The underlying philosophy for such an approach is to identify the absorptive capacity of the ecological (and economic) system (both in terms of size and speed of temperature change). The emission target would then be set so as to limit the (expected) temperature rise due to the greenhouse effect to what is considered to be without serious disruptive effects to environment and economy ('acceptable' or 'ecologically manageable' warming). KRAUSE/BACH/KOONEY(1990), for example, argue that the average rate of warming should be limited to about 0.1°C per decade, while currently a warming commitment of 0.2-0.5°C per decade is being added. However, there is no general agreement yet on whether such a limit can be specified. The Commission, for example, has stated in its Communication on Community policy targets on the greenhouse issue (SEC(90)496) that it is not yet possible to fix such levels in a scientifically sound way. Thus, in the absence of complete information, the precautionary principle has to serve for identifying the desirable target.

In order to evaluate the "absorption approach" from the economic point of view, it is important to come back to the issue of uncertainty. How robust is the absorption approach towards errors in the definition of the absorptive capacity, i.e. to deviations of the assumed capacity from the "true" capacity? The answer to this question depends on the shape of the cost and benefit curves of greenhouse gas emission reductions. The steeper the cost function and the flatter the benefit function, the higher the costs of errors will be. To put it in non-technical terms: if the economic costs of reducing emissions by 25% are much higher than the costs of reducing emissions by only 20% while the benefits of both policies are broadly the same, then errors in defining the appropriate emission reduction target can be costly.[7] Under such circumstances, fixing quantitative targets is not the best approach to the problem from the purely economic point of view. (Note that this is by no means an argument against emission reductions, but only against this approach of achieving them!).

4.2.2. Fixing prices/costs: the "insurance" approach

The alternative approach to tackling the problem of uncertainty when defining a greenhouse policy is to start by asking what society is willing to pay in order to reduce the

[7] This can be illustrated by the very preliminary CO_2 emission reduction cost curves established in the European Community's JOULE programme (see COHERENCE(1991)). From these tentative calculations (illustrated in graph 13) it would appear, for example, that in the case of Belgium the reduction of CO_2 emissions by close to 15% (compared to the 1988 level) could cost approximately four times more than reducing emissions by only 10%. In some other Member States the cost curves appear to be even steeper than in the case of Belgium, pointing to significant costs of choosing the "wrong" quantitative target.

risk of global warming (therefore the analogy of buying an insurance against possible catastrophic effects of global warming). All measures to reduce greenhouse gas emissions which cost less than this upper limit are then implemented, independently of the resulting quantity of emission reduction.[8] The cost limit can easily be adjusted whenever new information leads to a reassessment of the risks of global warming.

Contrary to the case of the absorption approach described above, the flatter the cost curve, the higher are the economic costs of errors in defining the appropriate cost limit for emission reduction measures. Thus, if it is "cheap" to reduce emissions by an additional amount while the benefits of such a reduction are high, then the welfare losses of fixing too low a limit are potentially high.

4.2.3. Concentrating on carbon dioxide

Another possibility of reducing the dimensions of the greenhouse problem in order to simplify the analysis is to focus only on carbon dioxide. Such a procedure can be justified on three main grounds:

- First, CO_2 is the most important single greenhouse gas, accounting for over half of the greenhouse effect (see graph 1).
- Second, not only are sources and sinks of carbon dioxide emissions comparatively well understood and statistical data relatively comprehensive, but the necessary response technologies are also readily available. For other greenhouse gases, such as methane and nitrous oxide, this is currently not the case.
- Third, CO_2 is a "key" gas in the sense that its emission is usually combined with the emission of other gases that - directly or indirectly - have negative environmental consequences (e.g. CO, NO_x, SO_2 etc.).

On the other hand, the economic costs of neglecting the other greenhouse gases in elaborating a policy framework for emission reductions can be high. In fact, the more low-cost opportunities there are to reduce emissions of the other greenhouse gases (CFCs, nitrous oxide, methane), the higher are these costs. This is of particular importance in the case of CFCs, even after the recent London agreement. Also, the more possibilities there are of substituting CO_2 emitting activities by activities emitting other greenhouse gases (e.g. methane in the case of fossil fuel substitution towards natural gas), the higher are the costs of considering only carbon dioxide.

[8] This approach can also serve to illustrate the economist's insistence on a comprehensive and economically efficient policy approach: the more efficient policies are designed, the more greenhouse gas emission reduction can be attained with the money society is willing to spend.

5. ENERGY USE: CHOICE OF INSTRUMENTS AND INSTRUMENT SETTING

As the production and use of energy is considered to account for approximately 50% of the enhanced overall radiative forcing resulting from human activities (see IPCC(1990c)) and for an even higher share of CO_2 emissions in the Community, the following analysis will only focus on the issue of energy.

5.1. Categories of available instruments and choice criteria

For a discussion of the available policy instruments to reduce energy related emissions of greenhouse gases, it is useful to distinguish three broad classes of instruments (even if in the end a combination of different instruments were to be used):

- traditional regulatory instruments and voluntary agreements
- traditional market-based instruments
- regulatory/institutional reform to enhance or install the market mechanism

The subsequent discussion will in particular focus on the criteria of static and dynamic efficiency for evaluating the desirability of these different types of instruments from the economic point of view. Static efficiency implies that a given environmental target is attained with the least cost. Dynamic efficiency, in turn, requires that this also holds true over time. From an analytical point of view, an important mechanism for ensuring economic efficiency is the application of the 'polluter pays' principle, even if in practice there may be circumstances in which the implementation of this principle may be difficult and a more pragmatic approach has to be retained. In addition to the criterion of efficiency, other aspects are of importance for the choice of policy instruments, notably the question of equity (income distribution, inter-generational justice etc.).

5.1.1. Traditional non-market-based instruments

In the past, environmental policy mostly relied on different types of standards or norms set by regulation (so-called command-and-control approach). Concerning the issue of energy use, such standards fall in two broad classes:

- efficiency standards defining (minimum) degrees of energy efficiency for products or processes;

- emission standards setting (maximum) limits to the emission of pollutants (mainly gases).

Standards can be a highly effective instrument for environmental policy. This is particularly the case when it is important that specific limits are respected (e.g. to avoid threats to human health) or when economic instruments would be ineffective due to market imperfections (for example, consumers might not notice energy inefficiencies). However, some standards have the disadvantage of not being directly linked to emissions (e.g. building standards) and thereby offering some scope for evasive action.

In addition, there is a conflict inherent in any standard setting: from the point of view of static efficiency, the more types of equipment which are in reality different are treated equally by one uniform standard, the higher are the social costs of regulation. The reason for this is that a uniform standard for several types of equipment does not take into account the specific shape of the individual marginal cost curves, i.e. it does not exploit the specific advantages of individual technologies. On the other hand, the regulator is normally unable to set equipment-specific standards. In fact, this would require the knowledge of all the individual cost curves. The administrative cost of dealing with such a complexity would clearly be enormous. Moreover, as only producers are likely to have such detailed equipment-specific information, there is a potential conflict of interests and it cannot be ensured that governments would get unbiased information.

With a view to dynamic efficiency, the main disadvantage of standards is that they do not provide a permanent incentive to economic agents to look for new ways to reduce emissions or to improve efficiency beyond the legal standard. The regulator, though, is unlikely to change the standards whenever technical or other developments would call for such a change implying therefore that standards would normally be set either too high or too low.

An attempt to achieve results in terms of environmental quality similar to those attained by regulation without, however, incurring the considerable administrative costs and inflexibilities consists of voluntary agreements between producers or codes of conduct. These agreements have sometimes proved successful in the past and may be particularly suitable in situations where the number of producers (of a certain polluting product) is small.

5.1.2. Traditional market-based instruments

Market-based instruments are generally characterized by their use of the price mechanism for reaching a given environmental target. Their general advantage is that they give a permanent incentive to reduce pollution while at the same time allowing choice among different possibilities of reaching the same target. They therefore often allow a given reduction of emissions to be achieved at the lowest cost to society.

Generally, two classes of market-based instruments can be distinguished according to the way they use the market mechanism (see e.g. BONUS(1990) on this issue):

- Taxes and charges, which aim to "fix the price of emissions", thus leaving the decision on the size of the emission reduction to the individual economic agents.
- Tradable emission quotas, certificates or rights, which aim to "fix the amount of emissions", leaving the determination of the price (marginal cost) per unit of emission to the market.[9]

Although, in analytical terms, both instruments lead to equivalent results in equilibrium, there is clearly a link to the question of targets (section 4.2.). If an approach for limiting emissions is retained that relies on a quantitative emission target, a quantity based instrument a priori appears to be the logical choice. However, the final choice will also have to take into account the transaction costs of different instruments.

To the extent that environmental policy concerning air pollution has made use of market-based instruments in the past, this has traditionally been in the spirit of the "price

[9] In a certain sense, environmental policy has traditionally relied on a quantity approach when fixing pollution or emission norms. However, such norms have been mostly been in the form of unitary limit values without using the market mechanism for equalising marginal emission reduction costs.

approach" and making use of existing markets. In the CO_2 context four main types of such instruments are of potential importance:

(a) Taxes

Carbon tax:

From the economic point of view, the most evident tax would be a tax on the cause of the problem, namely on carbon dioxide emissions[10], i.e. a type of "climate protection tax". Theoretically, the most efficient way to define the tax base would be to levy the tax directly on actual emissions (in line with the Polluter Pays Principle), to apply the same tax rate to each emission unit and to locate the tax at the point where the technical possibilities for emission reduction exist (for details see EWRINGMANN/ HANSMEYER/STÄHLER (1990)). Under these circumstances, each individual "polluter" will tend to reduce his/her emissions of CO_2 up to the point where the marginal cost of reducing emissions by an additional unit would equal the level of the tax rate on this pollution unit.

TABLE 4

INDICATIVE CO_2 EMISSION FACTORS FOR SELECTED FOSSIL FUEL PRODUCTS

	T CO2 / TJ
Hard coal	94
Coke	108
Brown coal	105
Primary oil	75
Motor spirit	72
Kerosene	72
Diesel oil	74
LPG	65
Natural Gas	55

Source: *Commission (1986)*

As there is - at least at present - a direct linear relationship between fossil fuel input and CO_2 emissions, both approaches are basically equivalent.[11] From the practical point of view, the choice between these two possibilities then has to be

[10] In principle, the tax should be on net emissions, as it is not gross emissions that cause atmospheric concentrations to change. However, as carbon sinks are largely unrelated to energy use, the distinction between gross and net emissions is of little importance for the design of a carbon tax on fossil fuels. Thus, only if a global CO_2 emission tax were envisaged, either would net emissions have to be taxed or could tax credits for CO_2 'sinks' be given.

[11] In the long-run, it would have to be ensured that a tax on fossil fuel use as opposed to a tax on CO_2 emissions does not work as a disincentive to the development and use of end-of-pipe CO_2 abatement technologies.

made on the basis of where the transaction costs are lower. However, due to the different carbon content of different types of fossil fuels (see the emission factors in table 4), a uniform tax rate on carbon emissions would imply, per thermal unit, a higher tax rate on coal than on oil and, in particular, than on natural gas (see table 5). A carbon tax therefore gives an economic incentive to substitute non-fossil fuels or fossil fuels with a low carbon content for fuels with a high carbon content.

TABLE 5

CONVERTING AN ECU 50 PER TONNE CARBON TAX TO AMOUNTS PER UNIT OF OIL, NATURAL GAS AND COAL

FUEL	COAL	OIL[1]	GAS
Physical unit	Tonnes of coal equivalent	Tonnes	Giga Joule (Gross Calorific Value)
Price per physical unit EC January 1987[2] Household sector Tax paid prices	ecu 228.25	294.40	6.55
Giga Joule (Net Calorific Value)	29.3	40.0	0.9
Price per GJ	ecu 7.79	7.36	7.28
Tonnes of carbon per GJ	0.0257	0.0200	0.0153
Tax per tonne C	ecu 50	50	50
Carbon tax per GJ	ecu 1.29	1.00	0.77
Percent of price in January 1987	17	14	11

1 Heating gasoil
2 Weighted by the 1987 structure of consumption in the different countries

<u>Source:</u> *Eurostat*

With respect to the definition of the appropriate tax base, basically four possibilities exist:

(i) Direct measurement of emissions: as set out above, this would appear to be the most effective way. However, the transaction costs are bound to be very high, probably overcompensating the advantages in terms of efficiency.

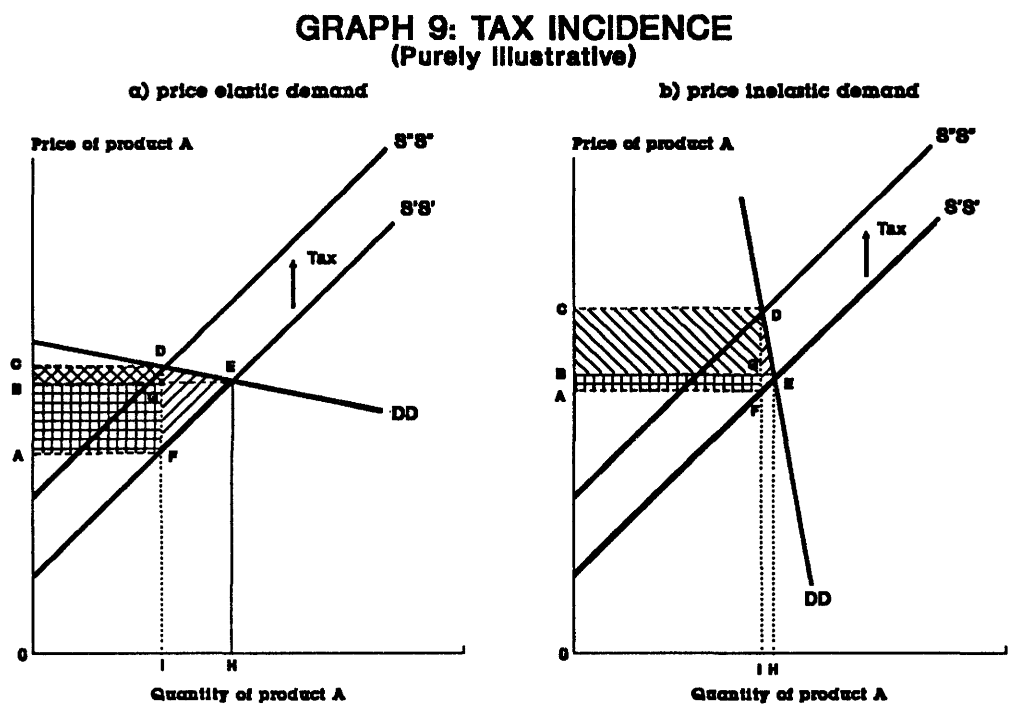
(ii) Declaration of emissions: although such a procedure would significantly lower the costs, the control problems are likely to be enormous.

(iii) Direct measurement of fossil fuel use: while for liquid fuels this might be a good solution both for stationary and for mobile sources (e.g. cars), the case of solid fuels like coal would probably pose some problems.

(iv) Declaration of fossil fuel use: although the transaction costs are bound to be lower than in the case of direct measurement, such a procedure realistically can only be envisaged for the business sector.

Concerning the question of whether a tax on emissions or a tax on fossil fuel input should be retained, one additional aspect is of importance: a tax on the use of fossil fuels could either be levied on those using the energy (consumption tax), or alternatively on those producing, importing or delivering fossil fuels (production tax). This would undoubtedly have significant advantages in terms of lower transaction costs, in particular as existing administrative infrastructures could be used.

However, it would also represent a shift away from an emission tax to a form of product tax. As a result, the tax would no longer be directly paid by the "polluter". Instead, the tax burden on the CO_2-emitter would only be determined indirectly, depending on how much of the carbon tax the fossil fuel producer/importer can pass on to his/her customer. This so-called tax incidence is essentially a function of the market conditions as is illustrated by graph 9: ceteris paribus, the flatter the demand curve for energy products (DD) - i.e. the more sensitive demand is to price changes - the less the tax can be passed on to the customer. In graph 9 this is represented by the respective size, in the two diagrams, of the area ABGF (loss of producer surplus) and BCDG (loss of consumer surplus). It can be seen that the gross burden of taxation is shared differently between individual economic agents, depending on the price elasticity of demand. The more price elastic demand and the less price elastic supply are, the higher the producer's burden.



The total burden of the tax may exceed the tax revenues collected (area ACDF) because of an excess burden (DEF). This excess burden (or deadweight loss) measures the distortions introduced by interfering with the consumer's free choice.[12] It is of crucial importance, however, to take any accompanying benefits into account. Thus, if the original market equilibrium (E) represented a sub-optimal resource allocation (e.g. because of the existence of external costs or an insufficient provision of public services), then the introduction of the new tax may imply a net gain and not a loss for society. It is important to keep this in mind, as the main argument for the introduction of a carbon tax is precisely the existence of externalities and therefore the correction of a sub-optimal allocation of resources through the free market.

Although the issue of tax incidence represents a short-coming of a product tax compared to a pure emission tax, a carbon tax imposed on fossil fuel use and administered at the level of fossil fuel producers or importers on the basis of declared quantities would appear the most preferable solution in view of the existing administrative infrastructure.

The main characteristic of a carbon tax compared to a carbon charge (discussed further below) is that the tax revenues are allocated to the general government budget. When analyzing the (macro)economic impacts of a carbon tax (see section

[12] If, for example, a consumer can no longer afford to buy a certain product after the tax increase, this loss in utility is not compensated by an increase in tax revenues.

5.2.2.), the budgetary repercussions of the tax are of crucial importance. Basically, the following two distinctions have to be made:

- budget balance improving versus budget neutral tax: Given a plausible set of demand and supply elasticities, the introduction of a carbon tax leads to an increase in tax revenues and - with unchanged expenditures - to an improvement in the government balance. In a Keynesian framework, this improvement in the government balance corresponds to a reduction in aggregate demand and may, therefore, lead to a negative GDP response. In order to avoid such a response, either government expenditures can be increased or other revenues can be decreased such as to keep the budget balance unchanged.

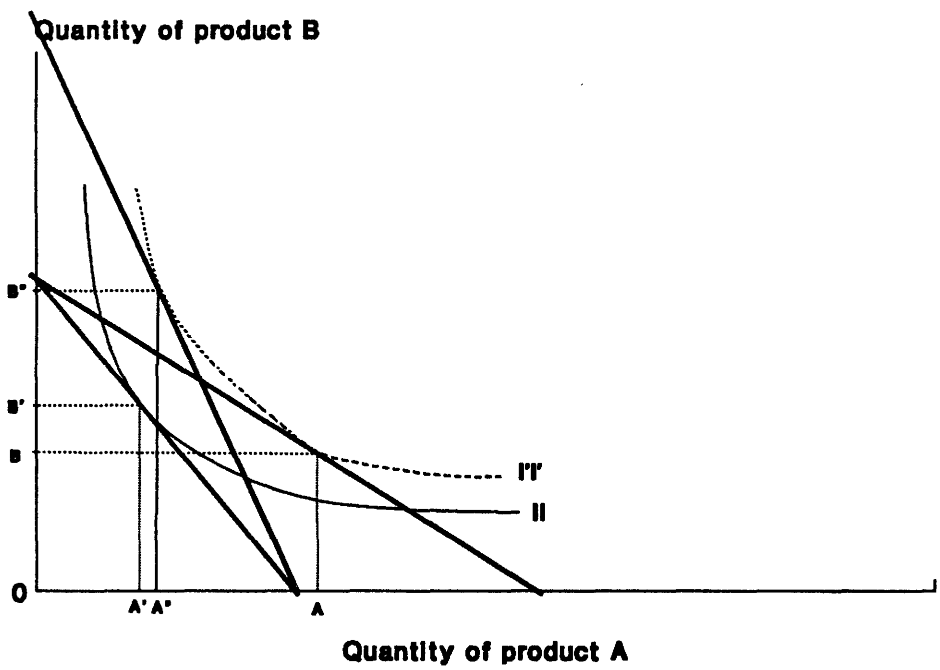
- revenue raising versus revenue neutral tax: if the additional revenues from the introduction of a (carbon) tax are not compensated by a reduction in other taxes, the overall tax burden in the economy increases. This, in turn, may have a negative effect on aggregate supply. In the revenue-neutral case, on the other hand, other taxes are lowered such as to leave the overall tax burden of companies and households unchanged. Thus, a revenue neutral tax only changes the structure of taxation - thereby inducing a change in relative prices - without changing the overall level of taxation.

  This issue of a change in the structure of taxation (or "fiscal reform") merits some further discussion. Analytically, energy can be seen as one of several production factors. If, therefore, one takes the position that presently more energy is used than would be optimal from the point of view of society (e.g. because energy prices do not reflect the full social costs of energy use), while other production factors (for example labour) are under-used (high unemployment), a redistribution of the tax burden from one production factor to another would not only incur no resource costs, but would even increase social welfare as it would eliminate an economically inefficient allocation of resources. Such a change would, however, imply short-run adjustment costs associated with the shift from one factor input combination to another (e.g. the replacement of existing energy-inefficient equipment). Moreover, there would of course still be significant net impacts at the microeconomic level: those burning large quantities of fossil fuel would be worse off, while those using non-fossil energy would be better off. Although this is exactly the intended incentive effect of the tax, undesirable distributional consequences might have to be compensated for (see section 5.2.2.).

Clearly, while revenue neutrality implies budget neutrality, budget neutrality does not imply revenue neutrality. In environmental terms, a budget balance improving carbon tax tends to reduce emissions by more than a budget neutral tax. This is because the emission reduction is not only the result of a substitution process between products subject to the carbon tax and products less affected or unaffected by the tax, but is also the result of an income effect. In economic terms, on the other hand, the revenue neutral introduction of a carbon tax is particularly appealing as it offers the potential for reaching a given emission reduction target with least (macro)economic cost.

This aspect is crucial in understanding the difference between the historical experience of the oil price shocks and a budget-neutral domestic increase in energy taxes. While in the former case there is a flow of real resources to oil-producing countries, in the latter case there is only a change in (domestic) relative prices. This distinction can also be illustrated with the help of the standard textbook figures depicted in graph 10. Before the introduction of the tax, a representative consumer consumes quantity A of product A and quantity B of product B. To the extent that the introduction of a tax on product A leads to a price increase for product A with the price of product B being unchanged, the household income constraint implies that the consumer can now only afford quantities A' and B', respectively, implying a lower overall level of utility (indifference curve II instead of I'I'). If, however, the tax induced price increase of product A is compensated by a tax (cut) induced price decrease for product B, the consumer can maintain his utility level and now reaches a new equilibrium by consuming A" and B" quantities, respectively. If product A is assumed to be the CO_2 emitting product, it can be seen from this illustration that while the pure substitution effect implies a higher emission level than the combined income and substitution effect (A" instead of A'), it also implies a higher level of consumer utility.

GRAPH 10: SUBSTITUTION AND INCOME EFFECT
(Purely illustrative)



One further characteristic of the carbon tax, and indeed of taxes in general, has to be mentioned in this context. Due to the imperfect knowledge of the respective elasticities, the quantitative outcome of a tax in terms of emission reduction is difficult to forecast. Thus, if the attainment of a specific emission reduction target is of importance (which, as has been argued in chapter 3, is not necessarily the case concerning carbon dioxide), tax rates probably have to be adjusted in a process of "trial-and-error". Such tax rate adjustments may, however, increase uncertainty with respect to future tax rates (and thus prices) and therefore have some undesirable effects on expectations.

Energy (Joule/Btu) tax:

One alternative to a carbon tax (which taxes energy products according to their carbon content) would be a tax based on the thermal content of energy products. From the economic point of view, it is difficult to justify such a general energy tax. As there is little reason to argue that, from the point of view of society, energy use per se is inherently negative, it is unclear why it should be taxed (and therefore in a sense be implicitly "punished"). It is therefore not surprising that in the ongoing discussion, two mainly political arguments are used for advocating a general energy tax.

- First, a carbon tax would tend to affect coal the most, due to its high carbon content. This might be considered undesirable both from the domestic policy point of view (in countries with domestic coal production) and from the point of view of supply security (coal, contrary to natural gas, is in comparatively abundant supply and a large part of coal reserves are located in "politically stable" industrialized countries). In economic terms, both these issues should really be dealt with by using other, more appropriate policy instruments (e.g. social policy and an oil import tax). In fact, basing the choice of a general energy tax on such arguments implies that a more costly approach to the greenhouse problem is retained than would be necessary.

- Second, carbon taxes increase the price of fossil fuels relative to non-fossil fuels. With unchanged policies, this also leads to an improvement of the competitive position of nuclear energy which might, in turn, be politically unacceptable.

  Again, seen from an economic stand-point, such a line of reasoning is untenable. As a matter of fact, there are two possibilities: either nuclear energy is economically viable from the point of view of society (i.e. taking into account the full cost of nuclear energy and considering the welfare losses occurring through the fact of imposing a technology which is strongly opposed by a large part of society). In this case there is no economic reason to neglect the "nuclear option". Or nuclear energy only appears economically profitable because some of its (hidden) costs are borne by society. In this case the appropriate policy strategy would not be to avoid a carbon tax but instead to ensure that the full cost principle is applied to all forms of energy and not only to fossil fuels.

Road transport fuel tax:

Another policy option that is sometimes proposed in the context of a reduction of CO_2 emissions is an increase in gasoline and diesel taxes. Such an increase is usually advocated by reference to the large (and in many countries rising) part of transport in overall emissions and the administrative ease with which it can be implemented. However, economically a petrol tax on its own is an inefficient instrument for reducing CO_2 emissions. This is not only intuitively clear (as emissions should be reduced where this is cheapest and there is no reason to believe that this is necessarily in the area of personal transport), but has also been shown empirically. NORDHAUS(1989) as well as CHANDLER/NICHOLLS(1990) have demonstrated that a petrol tax would be significantly more expensive to reach a given emission reduction target.

Concerning the choice between a carbon, energy or petrol tax, it has to be emphasised, though, that it is necessary to clearly define the policy aim. If the aim is to find the most cost-effective policy instrument to reduce CO_2 emissions, the carbon tax is clearly preferable. However, if other objectives are of importance, for example increased supply security or improved trade balance, a petrol tax may under certain circumstances offer higher overall benefits (see CHANDLER/NICHOLLS(1990)). Moreover, when evaluating the economic impacts of different types of taxes, it has to be taken into account that the sectoral effects are likely to differ significantly.

(b) Charges

Instead of a carbon tax, a carbon charge could be envisaged. Whilst a charge would have basically the same characteristic as a tax with respect to the direction of effects on the price of different fossil fuels, the main difference concerns the use of the revenues arising from the imposition of the tax or charge (see e.g. TEWINKEL/HANSJÜRGENS(1991) on the issue of taxes versus charges). In the case of a tax, the corresponding revenues would be attributed to the general budget and could be used for a restructuring of the general budget as set out above. In the case of a carbon charge, on the other hand, the revenues would, in the scheme currently under discussion, be earmarked to finance measures to reduce emissions (for example the funds could be allocated to a climate protection fund). The purpose of a charge therefore can be described as raising the revenues needed to pay for certain specific expenditures from those who are benefiting from these expenditures (a well-known example is waste water treatment charges).

Thus, while the main emission reducing mechanism of a carbon tax is normally the incentive effect, the purpose of a carbon charge is mainly (but not exclusively) revenue raising. The **advantages** of a charge over a tax are mainly twofold. The first main advantage lies in the availability of an emission reduction potential that would be difficult to exploit by mere reliance on the price mechanism. Publicly funded information campaigns, for example, might result in higher emission reductions than limited increases in energy tax rates as many small consumers might be unaware of the existing saving potential. As a result, the rate of carbon charge needed to raise the required amount of funds could be much lower than the carbon tax would have to be in order to reach a given CO_2 emission reduction target. Second, as the revenues from a charge would be earmarked for specific emission reduction measures, the revenue use would be relatively transparent and a charge might therefore face fewer acceptance problems than a tax.

On the other hand, there are three main **objections** that can be raised against a carbon charge:

- First, from a public finance point of view, the decision on the optimal allocation of public expenditure should, in general, not be linked to the decision on the sources of revenue. Although in certain circumstances such a link may be justified (e.g. user charges), this is unlikely to be the case in the context of CO_2 emissions. A CO_2 charge would therefore introduce undesirable budgetary rigidities.

- Second, without any adjustments, a carbon charge would tend to raise the overall burden of taxes and charges in the economy. It would therefore increase the share of GDP that is controlled by the public sector (although not necessarily by the government and therefore, indirectly, by the parliament), which might be politically and economically undesirable.

- Third, the funds raised by the carbon charge would in all likelihood also be used to finance - at least partly - emission reduction investments undertaken by private economic agents (companies or households). However, against such a procedure the same methodological reservations can be raised as against subsidies in general (see below).

- Fourth, in order to adequately administer the use of the revenues from a carbon tax, a new bureaucracy is likely to be required.

In addition to these objections, there are also a number of legal questions that are of importance: While taxes are part of the general budget and can thereby be redistributed according to standard budgetary rules (nationally and internationally), charges are generally considered to require a closer link to the user (user charge) or emitter (emission charge). This renders a reassignment of the funds legally more difficult.

(c) Fiscal incentives

The last category of instruments of importance in the context of greenhouse gas emissions consists of different forms of financial incentives. Such incentives can either take the form of tax incentives (e.g. reduced tax rates, tax exemptions etc.), or they can consist of fiscal incentives in the form of direct financial transfers (e.g. grants, "soft" loans etc.). Tax incentives are often easier to administer than direct financial transfers, while the latter can frequently be focused more easily on specific target groups. As already stated above, the amount of emission reduction per monetary unit can be much higher for such a fiscal incentive than for a tax. However, (implicit or explicit) subsidies are in clear contradiction to the Polluter Pays Principle (PPP), as the polluter is not (or at least not fully) paying for the cost associated with the abatement of the emissions. The risk therefore arises that the polluter undertakes less pollution abatement investment on his own than he would have done otherwise, in anticipation of public subsidies. For these reasons, there are severe economic objections to a general and widespread use of subsidies as a policy instrument (static and dynamic inefficiency).

In addition, it has to be kept in mind that fiscal incentives imply either a loss of government revenue (tax incentives), or an increase in government expenditure. Both would have to be compensated for by raising (other) revenue in order to keep the government budget balance unchanged. The economic costs of raising such additional revenues have to be deducted from the (emission reduction) benefits arising from the fiscal incentives. As far as the implementation in the Community context is concerned, there is also the legal question of to what extent Member States are allowed to pay subsidies (to promote energy saving investments in the business sector) without Community agreement. Within the GATT as well, legal (or political) complications might arise.

Nevertheless, there are specific circumstances in which fiscal incentives can be an effective and even efficient instrument. This is particularly the case when the transitory use of subsidies helps to create a market where it would otherwise not exist or where subsidy schemes specifically accelerate the rate of penetration of new, "green" technologies.

5.1.3. Regulatory/institutional reform to enhance or install the market mechanism

While the instruments described in the previous section all rely on existing markets, there are at least two broad classes of policy instruments which attempt to solve the pollution problem by creating new markets.

(a) Tradable permits

The basic idea of tradable emission rights[13] is to use the market mechanism for equalizing the marginal cost of emission reductions undertaken by different emitters. Tradable emission rights can be used either as a national policy instrument for limiting a country's emissions or as an international policy instrument for limiting aggregate emissions of a group of countries (see e.g. MARKANDYA(1991)). The underlying philosophy of tradable emission rights can be illustrated by an example: if a producer (A) is only allowed to emit a certain amount of CO_2, this target has to be met irrespective of the costs associated with it. Even if another producer (B) could reduce his emissions by the amount for only half the cost, fixed quotas would not allow these cost differences to be exploited. If, instead, trading is permitted, producer A could offer producer B a side-payment for reducing his emissions by more than he would have done otherwise. As the size of this side-payment would be lower than the emission reduction cost of producer A, but higher than the emission reduction cost of producer B, both producers would gain from such a "trade". Economists call this a "pareto-superior" situation.

Concerning the design of a marketable permit scheme for dealing with the issue of CO_2 emissions, it is necessary to rely principally on the (moderately successful) practical experience made in the United States (see e.g. HAHN(1989), HAHN/HESTER(1989a+b), TIETENBERG(1990)). The main mechanisms that have been used in these trading schemes are:

(i) Netting: In the US, netting allows modifying or expanding emission sources to avoid stringent review processes so long as the net increase in the emissions from a specific pollution source is below a certain threshold (so-called internal trading). If, for example, there were a CO_2 emission trading scheme for utilities in the European Community, each utility could expand its fossil fuel based generating capacity provided increased efficiency or fuel switching would allow the overall level of its CO_2 emissions to be kept constant.

(ii) Offsets: The basic idea is that new or expanding pollution sources are required to secure sufficient offsetting emission reductions from existing pollution sources so that after their entry or expansion the air (or water) is cleaner than before (both internal and external trading). Transposed to the CO_2 issue, offsets could, for example, mean that a company wishing to increase its CO_2 emissions either would have to find another company willing to reduce its emissions by the same

[13] In this paper, the terms "emission rights" and "emission permits" are used as synonyms. However, the "right" to emit can take two forms: on the one hand, it can be in the form of a certain quantity of emission per unit of time (e.g. per year); in the literature, the term "tradable permit" is usually understood in this sense. On the other hand, the right can also be in the form of a certain quantity of emission independently of the time of emission. This can be implemented in the form of "emission certificates" (see e.g. HEISTER/MICHAELIS/MOHR(1990)). This distinction between a "permanent" right and a right "per unit" is of particular relevance as far as the issue of "new entrants" is concerned.

amount or would have to guarantee an equivalent amount of reforestation to be undertaken in order to absorb the additional amount of emissions.

(iii) Bubbles: Under this mechanism, several (regionally grouped) emission sources are treated as if they were enclosed in an imaginary bubble. Only the total emissions (i.e. the sum of the different sources) that leave the bubble are set by regulation. Thus, in essence, the sources are free to choose the emission control measures among different discharge points as long as the overall emission (reduction) target is respected. In the CO_2 context, for example, the Community could be considered as one "bubble" as it is of no importance for the atmosphere whether the CO_2 is emitted in Member State A or in Member State B. Only the total amount of emissions has to be controlled.

(iv) Banking: Polluters are allowed to 'store' emission permits that have not been 'used' either for future use or sale. Due to the long life-time of greenhouse gases in the atmosphere, banking would theoretically appear to be a plausible option as - within a broad range - the year of the emission is of no importance for the climate. However, banking could complicate the scheme administratively. Moreover, permit "hoarding" might impair sufficient trading of permits thereby endangering the efficient functioning of the market. (Providing for the possibility of permit leasing would probably reduce the risk of hoarding.)

One of the most difficult aspects of any marketable permit scheme is the question of how the permits should initially be allocated among the participants (see e.g. GRUBB/ SEBENIUS(1991) for the issue of permit allocation in the context of an international emission trading system). In principle, three main alternatives can be distinguished:

- **allocation on the basis of the "grandfathering principle"**: in this case, permits would be distributed on the basis of past (or present) emissions. Initially, there would therefore not be an immediate need to trade, while gradually the gains from trading could be realized. However, this allocation principle has the characteristic that, implicitly, those polluters that have already made a significant effort to reduce their emissions in the past are put at a disadvantage compared to heavy polluters. In addition, the question of how new producers should be dealt with has to be decided.

- **allocation on the basis of indicators**: such a solution allows the use of one or more indicators (e.g. population and GDP internationally or employment and production at the national level) for devising an allocation mechanism.

- **allocation by auctioning permits**: in such a scheme, permits are auctioned publicly, thereby immediately creating a market (which is not necessarily the case for the other two allocation principles).

Concerning the use of a tradable permit scheme in the context of a policy to reduce CO_2 emissions, a few general comments are required. Theoretically, tradable permits are a very appealing instrument for reducing CO_2 emissions. It is not only an economically efficient scheme, but has also the additional advantage of signalling the scarcity of natural resources to the individual economic agent. While taxes follow Pigou's idea of internalising external costs into the price of goods, tradable emission rights follow Coase's approach of allocating property rights. These property rights can then be traded.

Like taxes, tradable permits can be applied either at the national or the international level (see section 7.1.2.). At the national level, for example, one could even envisage auctioning the right to produce or import a specified amount of CO_2 in the form of fossil fuels. This amount could be lowered over time in order to reduce CO_2 emissions. Thus, the quantity of emissions could be easily adjusted. Moreover, contrary to the case of taxes, a permit scheme guarantees that a quantified overall emission target is respected, provided, of course, compliance is ensured (see DUDEK/ TIETENBERG(1991), for example, on the monitoring and enforcement of greenhouse gas trading). Due to the fact that tax elasticities are uncertain, tax rates probably would have to be adjusted several times in a trial-and-error process in order to attain the specified target. This is an important aspect, as there often appears to be, in the political sphere, an affinity with the concept of quantitative targets.

On the other hand, there are some arguments that could speak against a tradable permit scheme:

- First, transaction costs could potentially constitute an obstacle to the efficient functioning of a tradable permit scheme. In this context, the experience with emission trading in California appears to suggest that while transaction costs are significant (10-30% of total costs), they do not appear to be responsible for paucity of trading (see DWYER(1991)). Transaction costs may explain, however, why most trading so far has been (company) internal and not external. Generally, the Californian experience illustrates the obstacles for creating an ideal, competitive market. For these reasons, marketable permits are likely to be best suited to situations where the number of participants is high enough to avoid problems of monopoly or oligopoly, but also low enough to keep transaction costs small.

- Second, unless auctions are used for allocating permits, a permit scheme for existing sources could pose a problem for new entrants. While the auctioning of emission rights at the national level appears to be a straightforward solution (see e.g. HEISTER/MICHAELIS /MOHR(1990)), it is likely to be more difficult to accept at the international level (even if the equity aspect of the permit allocation could be taken into account by an appropriate redistribution of the auction revenues).

- Third, while the likely tax burden in a scheme of emission taxes can be relatively easily assessed in advance, the future price of permits might be difficult to forecast. Companies (and probably also countries) might therefore prefer taxes to tradable permits.

- Fourth, a tradable permit scheme would require a monitoring mechanism (including possibly a system of fines for cases in which emissions exceed the allowed amount). Such control mechanisms could imply the need for new institutions.

(b) Other market creation and market enhancement measures

One of the major categories of attempts to exploit the existing economic potential for reducing energy demand and consequently energy related greenhouse gas emissions at the national level - mainly in the utility and residential sector - consists of concepts like "least-cost planning", "demand side management", "all sources bidding", "contracts for energy management" or "third party financing". The underlying philosophy of all these concepts is to install or to strengthen the market mechanism in areas where - for institutional, behaviourial or other reasons - it did not (sufficiently) apply before. As these types of instruments mainly focus on the specific area of energy conservation, they will be discussed in detail in section 5.3.1.

As a conclusion of the above discussion of the choice of policy instruments, there is a strong a priori reason to suggest that market-based instruments are a particularly useful component of an instrument-mix addressing the problem of global warming (see also BARRETT(1991b) and BERTRAM/STEPHENS/WALLACE on this issue).[14] In addition to the general efficiency arguments given above, three further arguments support this view:

- First, there are no direct negative effects of CO_2 emissions (e.g. health hazards etc.) that would call for a regulatory intervention.

- Second, the regional location of the emission source is of no importance, i.e. there is no so-called hot-spot problem.

- Third, basically all areas of economic activity are involved in the emission (and sometimes also the absorption) of carbon dioxide due to the combustion of fossil fuels. The combination of a large number of economic agents with a large number of technologies of energy use in fact suggests the use of broadly-based policy instruments rather than individual regulation.

However, this should not be interpreted as implying that market-based instruments are necessarily preferable under all circumstances. There are indeed cases, for example in situations with very high transaction costs of market-based instruments or with very low price elasticities, where regulatory means are superior, also from the economic point of view. Thus, the optimal policy-mix is often likely to consist of a combination of regulatory and market-based instruments and would be accompanied by other policies (e.g. in the fields of transport, energy, research and development, training and education, development etc.).

5.2. Addressing the issue by choosing the "top-down" approach: using the price mechanism

Following the above emphasis on the role of the price mechanism also influences the choice of the overall approach to the CO_2 emission limitation question. In this context, the so-called "top-down" approach takes a more aggregate, macroeconomic view of the problem. Its underlying philosophy can be explained as follows: The starting point is the observation that the actual quantity of emissions exceeds what is considered to be the

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[14] Although, unfortunately, there are very few studies directly comparing the costs of using "command-and-control" instruments as opposed to market-based policy instruments, the above presumption is not only theoretical. This becomes clear not only from TIETENBERG's analysis of the efficiency gains from tradable permit schemes, but it is also implicitly revealed by those studies quantifying the costs of CO_2 emission limitation policies not using the market mechanism (e.g. CSIS(1991)).

equilibrium amount. In market economies this is an indication of the fact that the "price" of emissions is too low. The reason for this lies in the existence of externalities or social costs: to the extent that the price of, say, fossil fuels paid by each individual economic agent does not cover the full cost (i.e. also the long-run environmental cost) of using this energy, the amount of energy used exceeds the social optimum.

From this analysis it is concluded that the most obvious way to reduce emissions is to increase the price of emissions by internalizing the social costs. In the context of energy related emissions (where, to a certain extent, a market for emissions implicitly already exists in form of a market for fossil fuel products - even if the price of the emissions may currently be zero), the aim is to ensure that energy prices equal the long-run marginal social cost of energy supply (or use). The general policy instrument for achieving this is taxation (table 5 gives an example of converting a carbon tax into energy price changes). In the absence of reliable, monetized estimates concerning the social cost of energy (in particular fossil fuel) use, a more pragmatic procedure is often used. In this case, the size of the tax rate is determined merely on the basis of what is required to reach a (politically predetermined) overall emission reduction target.

5.2.1. What tax/charge rates are required to reach given emission targets?

There already exist a considerable number of studies that have addressed this question (see table 6 for a survey of those studies focusing on carbon taxes). These studies not only cover a wide range of individual countries or world regions, but also apply analytical methods of different degrees of sophistication. Generally, three types of approach may be distinguished:[15]

- the price elasticity of energy demand approach
- partial equilibrium models
- general equilibrium models

When evaluating the results of those approaches or models that are based on the past, it should be kept in mind that a change in behaviour could also significantly change the conclusions in terms of required tax rates. In particular, there has never been, in the past, an occasion where energy was subject to a declared long-run progressive increase in taxation. If energy price expectations were altered by such a predictable change in taxation, then apparent price elasticities of demand calculated from past behaviour could underestimate the possible demand response. The reason for this is that, in reality, demand behaviour for energy consuming durable equipment is to a significant extent determined by price expectations, while statistical price elasticities are usually estimated on the basis of actual and not of expected prices. Nevertheless, past behaviour constitutes the best available scientific guide to what might be behaviour in the future. On the other hand, most studies assume technical progress to be exogenous. It is quite likely, though, that in the long-run an ecological reorientation of the economic sphere would also tend to change the direction of technical progress. As elasticities depend, among other factors, on the available technological options, such a change in the direction of technical progress would, in the long term, also change the observed energy price and substitution elasticities.

[15] BOERO/CLARKE/WINTERS(1991) use a somewhat broader distinction between theoretical models, statistical models and simulation models. Concerning simulation models, the authors distinguish between resource allocation models (general equilibrium models, restricted general equilibrium models, partial equilibrium models, bottom-up models) and macroeconometric models.

TABLE 6:

A SURVEY OF RECENT CARBON TAX STUDIES

Authors	Country/ Region	Emission reduction compared to baseline	Emission reduction compared to year	Simulation period	Approx. carbon tax[1] ($ t/C)	End of period GDP as % of baseline
MANNE/ RICHELS (1990)	World	-75% (in 2100)	OECD+USSR/EE -20% comp.to 1990; China+ROW:+ 100% comp. to 1990	1990-2100	250[2]	-4.0
BURNIAUX/ MARTIN/NICOLETI/ MARTINS (1991)	World	-37% (in 2020)	OECD+USSR: -20% in 2010 comp. to 1990; China+energy LDCs: +50% in 2010 comp. to 1990;: stabil. after 2010	1985-2020	215[3]	-1.8
EDMONDS/BARNS (1990)	World	-14% (in 2025) -36% " " -47% " " -70% " "	 stabil.comp.to 1985 -20% comp. to 1985 -50% comp. to 1985	1985-2025	27 95 136 436	 -3.1 -7.5
WHALLEY/WIGLE (1990)	World	-50%		1990-2030	460	-4.2[4]
BERGMAN (1990)	Sweden	-10% (in 2000) -20% " " -30% " " -40% " "		1985-2000	45 97 195 335	-0.02 -1.43 -2.57 -3.86
PROOST/ VAN REGEMORTER (1990)	Belgium	-28% (in 2005)	Stabilisation at 1987 level	1987-2010	380	-1.8[5]

TABLE 6: (continued)

A SURVEY OF RECENT CARBON TAX STUDIES

Authors	Country/ Region	Emission reduction compared to baseline	Emission reduction compared to year	Simulation period	Approx. carbon tax ($ t/C)	End of period GDP as % of baseline
GLOMSRØD et al (1990)	Norway	approx. -25% (in 2000)	stabilisation at 2000 level	1990-2010	(doubling of fuel prices compared to refer. sc.)	-2.7
CBO[6] (1990)	USA PCAEI	- 8% (in 2000)	+ 5% comp. to 1988	1991-2000	100	
	DRI	-16% " "	- 6% comp. to 1988		100	-2.0
	DGEM	-36% " "	-27% comp. to 1988		100	-1.0
	E/R	approx.-50% (2100)	-20% comp. to 1990	1990-2100	100	-1.0
JORGENSON/ WILCOXEN (1990b)	USA	-10% (in 2100)	stabil. at 2000 level	1986-2100	6	-0.2
		-20% " "	stabil. at 2000 level		15	-0.5
		-36% " "	-20% comp. to 1990		42	-1.1

FOOTNOTES:

1 At the end of the simulation period.
2 Long-run equilibrium value.
3 Average tax rate in the scenario without trading in emission rights. With trading the tax rate is only $ 152.
4 In the case of international taxes where costs are calculated as Hicksian equivalent variations. For national production taxes the costs are approximately the same, while for national consumption taxes they appear to be only half the size.
5 Note that welfare is only 0.2% below the baseline.
6 The CBO study compares three different models: the US Energy Information Administration model, the DRI quarterly econometric model, Dale Jorgenson's dynamic general equilibrium model and, for a long-run analysis, the Edmonds-Reilly model (only the results for a unilateral US tax are reported here). In the DRI model simulations, the carbon tax is phased in over 10 years.

NOTE: Some of the figures have been coverted from the authors' original data in order to improve the comparability. They can therefore only be considered as approximations (e.g. due to exchange rate assumptions).

(a) The price elasticity approach

The price elasticity approach is both the most easily applicable and the least sophisticated approach. On the basis of price elasticities of energy demand estimated with data from the past, is calculated the increase in prices that would be required to reach a given fossil fuel use and therefore CO_2 emission target. For the **United Kingdom**, BARRETT (1990b) has calculated the tax rates that would be required to reduce carbon emissions by 20% in the short- and in the long-run. On the basis of the elasticities he used, he derived tax rates of 151% on coal, 119% on oil and 57% on natural gas in order to reduce emissions in the short-run, implying a tax of £86 per ton of carbon. In the long-run, the tax rates would only have to be 40%, 32% and 15%, respectively (£23 per ton of carbon).[16] These estimations do, however, exclude the transport sector from the analysis.

TABLE 7:

PRICE ELASTICITIES OF FINAL ENERGY DEMAND IN THE EC

COUNTRY	SHORT TERM	LONG TERM
Belgium	-0.26	-1.05
Denmark	-0.16	-0.63
Germany	-0.11	-0.44
France	-0.10	-0.41
Italy	-0.14	-0.55
Netherlands	-0.16	-0.62
United Kingdom	-0.10	-0.42
USA	-0.09	-0.38
Japan	-0.09	-0.35

Source: *MITTELSTÄDT (1983)*

(b) Partial equilibrium models

Although the elasticity approach described in the previous section requires relatively little effort, it has the serious disadvantage of neglecting any feed-back mechanisms. Partial equilibrium models (which can be econometric, linear programming or process-oriented models) aim at integrating at least some of such mechanisms. Their characteristic is to focus on one or more, but not on all aspects of the problem. Only for those markets under

16 The importance of distinguishing the short run from the long run is also clearly illustrated in table 7 by the markedly higher long run price elasticities of aggregate energy demand compared to the short run elasticities.

explicit consideration is a market clearing mechanism analysed, while other variables are treated as exogenous. The most widely used partial equilibrium models in the context of CO_2 policies are models either only representing the energy sector or only focusing on macroeconomic variables. Partial equilibrium models are, compared to general equilibrium models, particularly suitable for analysing the medium-term economy-wide or energy sector adjustment dynamics in response to a carbon tax (even if they normally do not contain the high degree of sectoral detail of input-output models).

One such model has been used by KOUVARITAKIS(1989) to analyze policy options to reduce energy-related CO_2 emissions in the **OECD region.** The carbon tax scenario imposes a tax at a level equivalent to $50 per tonne of coal equivalent, approximately representing a price rise in the order of 100% for coal and 40-60% for crude oil and natural gas (compared to 1988/1989 figures). The results of the simulation indicate not only that most of the emission reduction is in the first five years, but also that emissions only fall by around 12% compared to the baseline in 2005. In spite of the fact that large-scale dislocation of energy intensive production to non-OECD countries has been excluded in the model, total world emissions are only 4% below the baseline. (This again illustrates the importance of a global solution.) The overall conclusion of the KOUVARITAKIS study is that measures would have to be large scale and costly in order to seriously affect long-term atmospheric CO_2 concentrations.

Within the framework of a broader study on a "Green Europe", DRI(1990) has simulated the effects of a tax of ECU 300 per ton of carbon for the **European Community** (major four). In terms of energy prices, the maximum effect of the tax on the level of energy prices is 49% for France, 52% for Italy, 71% for the United Kingdom and 75% for Germany. The effects of this tax, which is gradually phased in during the 1990s, is to nearly stabilize CO_2 emissions by the year 2000. There is, however, no reduction in emissions compared to the 1988 level. Moreover, in order to sustain the stabilization, further carbon tax increases are necessary.

Another analysis focusing on the Community has been undertaken in the context of the Commission's exercise "Energy for a new century" (COMMISSION(1990a)). In a scenario named "high prices" (scenario 4), the effects of the introduction of a carbon tax on fossil fuels and of an expansion in nuclear energy capacity has been investigated. The carbon tax represents a once-and-for-all increase in the price of coal of 100%, in the price of oil of 40% and in the price of natural gas of 30%. Economic growth is assumed to be similar to the rate assumed in the baseline. In terms of CO_2, emissions stabilize around the year 2000 at their 1987 level and decline thereafter to be 19% lower in 2010.

For the **United Kingdom** and within the framework of the JOULE programme, CAPROS/KARADELOGLOU/MENTZAS(1990) have combined two partial equilibrium models, one energy (MIDAS) and one macro-sectoral (HERMES) econometric model, to study the impact of a carbon tax. Four different types of scenario were distinguished, depending on whether structural adjustment in the power generation sector (notably a doubling of the nuclear and natural gas investment programmes by the year 2005) were included or not, and whether the carbon tax was additive (like excise duties) or multiplicative (like VAT, which turns out to be less effective). The general conclusion of the study is that carbon taxes have to be drastic (several hundred percent) in order to reach ambitious CO_2 reduction targets. In fact, the elasticity of emission reduction per unit of mean energy price increase is very small and only in the order of -0.17. The major part of the emission reduction is achieved by a decrease in total energy demand, while fuel substitution is only of secondary importance. The results show that structural adjustment in the power generation sector is of crucial importance for the scope of emission reduction. However, even with such an adjustment, it proves impossible to (realistically) reach the Toronto target. When interpreting the results of this study, it has to be kept in mind, however, that, in the model version used by the authors, investment decisions in the electricity generating sector are treated as exogenous. Thus, the important aspect of fuel substitution in electricity generation has not been captured satisfactorily.

A second study simulating the effects of a carbon tax for the United Kingdom has recently been undertaken by BARKER(1990). Barker simulated an ad valorem tax on domestic fossil fuel which is modulated according to the carbon content and rises each year by 3 percentage points in order to minimize adjustment costs (see below the discussion on timing). The tax is imposed unilaterally and is fully compensated by a corresponding reduction in VAT in order to keep the average consumer price level unchanged. The main conclusion of the study is that while the costs of stabilizing CO_2 emissions by 2005 at their 1990 level are relatively small, proportionally greater efforts are required to reach the Toronto target. Due to the fact that the easy substitution possibilities are exhausted before the year 2000, the tax rate has to increase by almost 10 percentage points per year in order to come close to a 20% reduction of emissions by 2005.

Also for the United Kingdom, but only for the manufacturing sector, INGHAM and ULPH studied what level of taxes on CO_2 emissions would be required to reduce the UK manufacturing sector's emissions to 80% of their 1988 level by the year 2005. On the basis of a vintage model of factor demands, the authors find that the required carbon tax level would be substantial: under a broad range of assumptions, the taxes on coal would have to be in the range of 123%-277% by the year 2005, on oil 57%-128% and on natural gas 71%-160%.

Concerning **France**, preliminary work undertaken by the COMMISSARIAT A L'ENERGIE ATOMIQUE(1990) analyzes the introduction of a progressively phased in tax on fossil fuels (oil and coal). The tax rate is constant in real prices and amounts to FF 850 per ton of oil equivalent. Two variants were simulated, one without any recycling of tax revenues and one in which employers' social security contributions are reduced in order to compensate for the effect of higher energy prices on the production cost of companies. In terms of emissions, CO_2 emissions are between 19% (revenue raising) and 13% (revenue neutral) below the baseline by the year 2010. It is interesting to note that SO_2 emissions decrease by even more (38% and 28%, respectively).

For the Federal Republic of **Germany**, PROGNOS(1989) analyzed the effects of higher energy prices and taxes on CO_2 emissions. Compared to the status-quo projection, it is assumed that (real) oil prices progressively rise to $ 35 per barrel by the year 2010 instead of 25 $/b. In addition, the energy tax rates on fossil fuels are doubled with respect to the baseline. These price effects are combined with accompanying measures to promote energy saving. This sensitivity scenario results in a primary energy demand 10% below the baseline and a reduction in CO_2 emissions of the same order.

(c) General equilibrium models

The short-coming of partial equilibrium models of neglecting important interactions has led to the development of (computable) general equilibrium models. In fact, a general equilibrium framework endogenously integrates all key economic sectors and permits economic agents in all sectors to optimize jointly. The integration of the main feed-backs and interrelationships between the different economic sectors allows the model to be solved for the general equilibrium of the entire system. In order to adequately assess not only the direct but also the indirect costs and effects associated with global environmental issues, a general equilibrium framework integrating economy, energy and environment is essential. However, for computational reasons, the present generation of general equilibrium models only focuses on a comparative static analysis of two or more equilibria.

Thus, although they are particularly suitable for an investigation into the long-run welfare effects of the introduction of a carbon tax, for example, they give little or no insight into the dynamics of the adjustment path.

One of the empirical attempts at applying the general equilibrium approach (although not yet a computable general equilibrium) at the **worldwide** level has been undertaken by MANNE and RICHELS (1991). The authors use a model distinguishing five major geopolitical groupings (Global 2100) to analyze the impacts of policies to reduce worldwide CO_2 emissions (-75% compared to the baseline by the year 2100). These overall reductions are brought about by emission reductions (20% compared to 1990) by the US, the rest of the OECD and Eastern Europe including the Soviet Union, while developing countries (incl. China) are allowed to increase their emissions to twice their 1990 level. The main conclusions of this study can be summarized as follows:

- The long-run equilibrium size of the carbon tax required in each region to reach the emission reduction target would be $250 per ton of carbon.

- There are significant regional differences in the time path to the long-run equilibrium, reflecting the different emission reduction possibilities. This illustrates the potential gains from allowing international trade in emission rights.

- Some of the regions (or countries) face considerable losses in GDP, representing the costs of the emission reduction policies. The costs differ, because some countries/regions find it more difficult than others to decouple GDP and energy growth. Moreover, as the low-cost carbon-free energy options are exhausted, the macroeconomic consequences begin to mount. As a result, OECD countries other than the USA would only incur overall GDP losses of less than 2 percent, while China would face GDP losses of approximately five times this amount.

- The crucial role of China is becoming apparent. If China is permitted to quadruple its emissions between 1990 and 2100 (instead of a doubling), then all other countries would have to reduce their CO_2 emissions to zero in order to attain the global emission target.[17]

Also at the **worldwide** level, William CLINE(1989) has conducted preliminary simulations with a model developed by Jae Edmonds and John Reilly in order to examine the size of energy taxes that might be required to achieve a stabilisation of CO_2 emissions. Imposing an arbitrarily set tax of 150% on coal, 100% on oil and 50% on natural gas, he finds that worldwide emissions can be cut from 9.6 billion tons of carbon in his baseline for the year 2050 to only 4.1 billion tons. Cline's results also show a large reduction in total energy use, suggesting that fuel substitution would be difficult and costly.

Another study of the costs of **worldwide** CO_2 emission reduction policies has recently been presented by BURNIAUX/MARTIN/ NICOLETTI/MARTINS(1991). On the basis of a 7-region world model and focusing on a 35-year time horizon, the authors simulate a "Toronto-type" agreement in which industrialized countries (OECD and USSR) cut their emissions, by the year 2010, to 20% below their 1990 levels and stabilize them thereafter. A less stringent constraint is applied in China and the energy-exporting LDCs. Under this scenario, the level of the carbon tax averages $215 per ton of carbon by the year 2020. The tax rate varies widely across regions, from only approximately $60 t/C in China to over $950 in the Pacific region. This wide dispersion across regions -reflecting differences in economic growth, the relative structure of fossil fuel prices and the mix of fossil fuels in

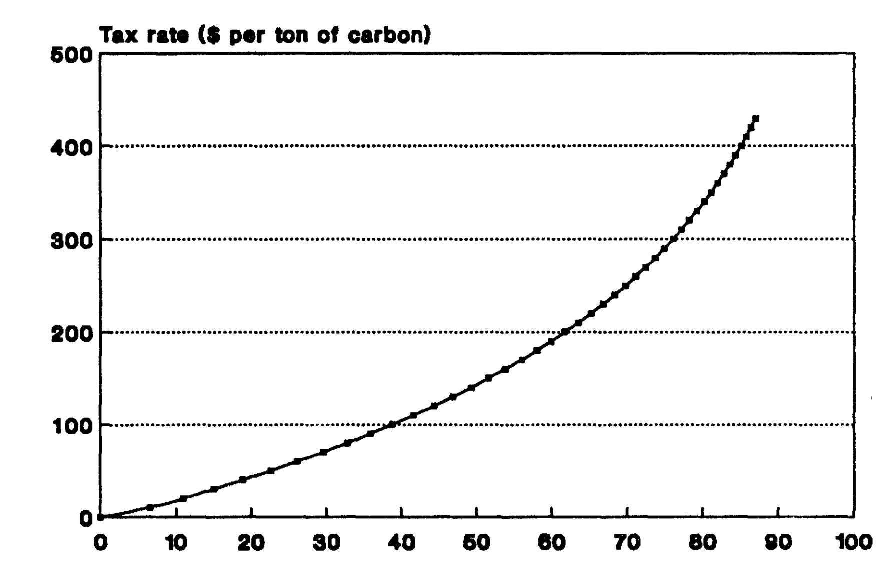
[17] For comparison: worldwide CO_2 emissions approximately quadrupled in only 45 years, between World War II and today.

energy demand - clearly illustrates the scope for a trade in emission rights. In a second scenario, all countries are therefore assumed to be endowed with an initial amount of emission rights and trading of such rights is allowed. As a result, the common tax rate amounts to only \$152 t/C in 2020, compared to an average of \$215 in the scenario without trading.

For the **United States,** the CONGRESSIONAL BUDGET OFFICE(1990) has recently published a study evaluating the effects of a carbon charge/tax on the basis of different partial and general equilibrium models (for the short-run: PCAEO, DRI and DGEM; for the long-run: Edmonds-Reilly). The simulations focused on a carbon tax phased in over a period of ten years. The tax starts at \$10 per t/C in the first year and reaches its maximum of \$100 t/C after ten years. By the year 2000 CO_2 emissions are between 8 and 16% below their baseline level, depending on the model. Over the longer run, the effects are significantly larger. Depending on the assumptions concerning the future trends of energy efficiency and new energy technologies, the tax rate required to keep emissions at 80% of their 1988 level varies between \$100 and \$250 per ton of carbon.

Another study applying the general equilibrium approach has been undertaken by GLOMSRØD/VENNEMO/JOHNSEN(1990) for the case of **Norway**. The analysis focused on the (unilateral) introduction of a tax on oil (which is the predominant type of fuel used in Norway). The tax revenues were redistributed in a lump-sum fashion. These revenues are rising over time, indicating that fuel taxation for environmental reasons can prove to be a stable source of income for the government. In order to stabilize CO_2 emissions at their level in 2000, fuel prices have to rise steadily and attain a level of roughly 100% of the baseline level in the year 2010. This relatively high tax level notably reflects the comparatively modest fuel substitution possibilities. The study at the same time demonstrates that the stabilization of CO_2 emissions also gives additional benefits in terms of a considerable reduction in the emission of other air pollutants.

GRAPH 11: "CONSENSUS" CARBON TAX CURVE



Source: NORDHAUS(1991b)

Concerning **Belgium**, PROOST/VAN REGEMORTER(1990) have analysed the feasibility and the effects of a carbon tax aiming at a 30% reduction in CO_2 emissions by the year 2005 compared to the baseline. Assuming a national carbon tax applying to Belgium only, the carbon tax rates required to reach the emission target are $189 per ton of oil equivalent (toe) for natural gas, $257 per toe for oil and $322 per toe for coal, respectively. The level of the CO_2 excise corresponds, on average, to a doubling of energy prices for oil.

Summing up the existing studies concerning the effects of carbon taxes on emissions, it is possible to derive an approximate average figure of the effectiveness of such taxes for reaching different CO_2 reduction targets. Such a function between the carbon tax rate and the level of CO_2 emission reduction has been calculated by NORDHAUS(1991b) in form of a "consensus" marginal cost/tax rate curve presented in graph 11.

5.2.2. What are the main economic effects?

(a) The macroeconomic effects[18]

As far as the macroeconomic effects of carbon or energy taxes are concerned, it is of crucial importance to consider the question of what happens with the tax revenues. If no change in expenditure or in revenue other than carbon/energy taxes is envisaged, virtually all studies show a significant reduction in GDP as suggested by the above theoretical analysis. However, if the tax revenues are redistributed, i.e. if the tax is budget-neutral, most econometric models result in only small GDP losses or, in a few cases, even a small positive effect.

Preliminary simulations using the HERMES models for Germany, France, Italy and the United Kingdom can illustrate this point (see DETEMMERMAN/DONNI/ZAGAME (1991)). The simulation exercise compares the (macro)economic effects of a tax on energy products calibrated so as to increase ex ante energy prices by 20% with and without redistribution of the tax revenues. If the tax is not revenue neutral, the level of real GDP is approximately between 1-2 percent lower than in the baseline after five years (on average -1.6; see table 8). If, on the other hand, tax revenues are redistributed to households via a reduction in income taxes, real GDP is even slightly higher than in the baseline in three of the four countries (-0.1 to 0.5%). A similar observation can be made in the case of a redistribution of energy tax revenues via employers' social security contributions. KAUFMANN/PAULY/ THOMPSON(1991) recently came to similar conclusions, showing that, in the case of revenue distribution, the loss in GNP growth is only 1/3 of that observed in the case of a tax designed to improve the budget balance.

Most other studies are broadly in line with these conclusions (see e.g. BYE/BYE/LORENTSEN(1989), BARKER(1990), COMMISSARIAT A L'ENERGIE ATOMIQUE(1990), DRI(1990), CHANDLER/NICOLLS(1990), GLOMSRØD/ VENNEMO/ JOHNSEN(1990), BRINNER/SHELBY/YANCHAR/CRISTOFARO (1991)). To give an idea of the broad order of magnitude, a 20% reduction (compared to the baseline) in CO_2 emissions by recurring to budget neutral changes in the tax system could have as a consequence that, after ten years, the level of real GDP could be between 0.5-1.5% lower than in the baseline. Expressed in terms of annual growth rates, GDP growth would be between 0.05-0.15 percentage points lower than in the reference

[18] For a comprehensive analytical survey and a recent up-to-date survey of the macroeconomic consequences of controlling greenhouse gases, see BOERO/CLARKE/WINTERS(1991). See also HOELLER/DEAN/NICOLAISEN(1991) for a recent survey of empirical studies.

scenario.[19] As can be expected, the more ambitious the emission reduction target, the higher the GDP losses are (see table 6).

Overall, therefore, these estimates of GDP losses appear to be comparatively small.[20] They clearly show that emission reduction is not necessarily in conflict with economic growth and prosperity. On the contrary, if the starting point is a situation with a sub-optimal tax system, the introduction of a carbon/energy tax and the accompanying reduction of other, highly distorting taxes (in the revenue-neutral case), then GDP may actually be higher after the introduction of the carbon tax than it would have been otherwise.

Despite these arguments, it is legitimate to analyze whether the possible GDP losses are a cause for concern from the economic policy point of view. After all, they normally imply losses in both income and employment. However, it should not be forgotten that GDP is only an imperfect welfare indicator. As "gross domestic product" only counts market transactions, it neglects an important part of what determines human welfare. To give an example, it is quite possible that increased pollution raises GDP in the short-run. This is because buildings have to be renovated, forests replanted, hospitals staffed etc. Nevertheless, few would argue that social welfare has increased. Note in this context that MANNE and RICHELS, who come up with high GDP losses of CO_2 reduction policies, clearly state in their paper that they do <u>not</u> attempt to estimate the <u>benefits</u> of slowing down the rate of global warming. Indeed, GDP losses would per se be no sufficient reason for rejecting an emission reduction policy. Only if these GDP losses correspond to losses in social welfare is the corresponding policy undesirable. However, as has already been mentioned above, some studies (e.g. GLOMSRØD/VENNEMO/JOHNSEN) estimate the benefits from CO_2 control policies other than mitigated global warming, i.e. the benefits in terms of improved health conditions due to improved air quality etc., to be roughly 2/3 of the calculated GDP loss of such policies.

As the employment effects of carbon taxes are usually closely linked to the macroeconomic consequences in terms of GDP, they need not be discussed in detail here. Suffice it to say that the (negative) employment effects of the introduction of a carbon or energy tax could be mitigated if not over-compensated if the tax revenues were used to reduce taxes or charges on labour.

Concerning the impact of the carbon/energy tax introduction on the general <u>price level</u>, it is necessary to distinguish the price level effect from the real income effect. While a rise in energy taxes would generally tend to raise consumer prices (to the extent that cost increases are passed on to consumers and are not compensated for by corresponding value added tax cuts) and therefore affect the measured rate of inflation, this does not necessarily represent a purchasing power loss for consumers, provided the tax revenues are redistributed to consumers via the income tax system. Moreover, as long as there is no

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19 This is also broadly in line with the results by JORGENSON and WILCOXEN(1990a), who calculated, in form of "counter-factual" scenarios using a general equilibrium model, the reduction in the annual GDP growth rate resulting from the historical oil price trends since 1972 to be in the order of 0.2% for the United States. However, as has been argued above, this experience was neither revenue neutral nor gradually phased in!)

20 It might be appropriate, at this point, to remind the reader that there are many examples of policies which are likely to incur such GDP costs (e.g. "energy supply security" measures). These (short-run) GDP losses are nevertheless considered acceptable in view of the expected long-run gains. One could therefore ask whether - in the light of the fact that almost 80% of Community citizens who are aware of the issue consider the greenhouse effect to be very serious (see EUROBAROMETER(1990)) -a reduction in the GDP growth rate by 0.1% p.a. would not be considered by many to be an acceptable "insurance premium".

price-wage spiral, prices would only rise once and there would be no permanent rise in inflation. However, the macroeconomic effects of the price level increase depend crucially on the monetary policy stance. Should monetary policy accommodate the price increase, output effects are likely to be very small. If, on the other hand, monetary policy remains unchanged, the resulting rise in interest rates could lead to noticeable output losses.

TABLE 8:

MACROECONOMIC IMPACTS OF DIFFERENT TAX SCENARIOS FOR EUR4

		Revenue raising tax only	Tax plus energy saving invest. subsidy	Tax plus reduction in employers' soc.sec. contr.	Tax plus reduction in personal taxes
GDP	1991	-1.47	-0.15	-0.53	-0.35
	1995	-1.55	-0.06	0.11	0.18
GFCF	1991	-0.78	7.03	0.28	-0.16
	1995	-1.57	5.16	0.32	0.04
Cons. prices	1991	2.56	2.71	1.57	2.57
	1995	3.69	4.10	2.00	4.12
Final energy cons.	1991	-3.69	-4.07	-2.98	-2.74
	1995	-5.67	-9.72	-4.40	-3.78

Source: *DETEMMERMAN / DONNI / ZAGAME (1991)*

(b) The structural and sectoral effects

More important, quantitatively, than the macroeconomic impacts are the structural and sectoral effects. Although the purpose of a carbon tax is precisely to encourage structural change away from carbon intensive fuels and energy intensive products or processes, it is here that the adjustment costs arise (quite apart from the political sensitivities). A priori, energy intensive sectors will be affected most by an increase in their total cost and the corresponding deterioration in competitiveness as a consequence of energy/carbon taxes. Thus, it is not only the energy sector that is directly concerned, but also some branches of basic industries (notably iron and steel, chemicals etc., see DRI(1990)) and, in particular, the transport sector (see also table 9).

On the other hand, the amount of emission reduction achieved in different sectors by imposing a uniform (carbon) tax depends not only on the energy intensity, but in particular on the price elasticity of energy demand, reflecting both technical substitution possibilities and behavioural responses. In the DRI study on "Green Europe", for example, the two areas in which emissions decrease drastically in response to a carbon tax are industry and the domestic and residential sector. This contrasts with only modest reductions compared to the baseline in the power generation sector and the transport sector. Although some argue for sectorally differentiated taxes in the light of these findings, such a conclusion is difficult to justify economically. From the economic point of view, the main advantage of a uniform tax is precisely that emissions are reduced where this is easiest. There is no reason why all sectors of economic activity should reduce emissions by the same amount.

TABLE 9:

SECTORAL OUTPUT EFFECTS OF A CARBON TAX IN NORWAY

Manufact. of industrial chemicals	-33.3%
Manufact. of pulp and paper	-20.8%
Petroleum refining	-14.8%
Manufact. of non-industrial chemicals and mineral articles	-14.7%
Wholesale and retail trade	- 6.7%
Manufact. of metals	- 6.1%
Domestic transport	- 5.3%
Manufact. of metal products etc.	- 4.9%
Finance and insurance	- 4.4%
Other private services	- 2.9%
Printing and publishing	- 2.5%
Manufact. of food	+ 0.3%
Manufact. of timber and wood products	+ 1.5%
Production of electricity	+ 1.7%
Construction	+ 6.4%
Manufact. of textiles	+ 7.0%
Housing	+ 8.4%

Source: *GLOMSRØD / VENNEMO / JOHNSEN (1990)*

In this context, it is also necessary to distinguish between domestic effects and effects due to international competition. At the domestic level, the economic sectors that are hit the hardest are those where fossil fuel represents a high share in total production cost and where substitution possibilities are limited (e.g. the chemicals industry). In the context of an open economy and a unilateral tax, on the other hand, industries open to international competition are likely to be the most negatively affected. It is, therefore, not surprising that in the case of a small, open economy like Belgium, for example, the sectoral output effects are much larger if the carbon tax is introduced unilaterally compared to a situation where it is introduced internationally (see table 10). For large countries like the United States or trading blocks like the European Community, the difference between unilateral or joint international action can be expected to be much smaller.

Moreover, one could argue that there are also industries that are likely to gain in the long-run from an early reorientation of research efforts and business strategies. The producers of energy efficient investment and consumer goods and their international market opportunities might serve as an example. This "first-mover-advantage" could be very significant in the case of a uni-directional trend towards higher fossil fuel prices.

TABLE 10		
SECTORAL OUTPUT EFFECTS OF A CARBON TAX IN BELGIUM		
	Belgium only	Belgium and ROW
Energy sectors	-17.7%	-10.8
Energy intensive industries	-16.2%	- 3.4
Non-energy intensive industries	+2.3	- 0.5
Tertiary sector	+0.4	+0.0
Source: *PROOST / VAN REGEMORTER (1990)*		

(c) The distributional effects

One aspect that has been subject to relatively little empirical analysis is the question of distributional effects. In particular, no study is available yet on whether these distributional effects differ strongly between Community Member States. Generally speaking, these effects can occur at the same time nationally and internationally. Concerning the domestic income distribution, empirical studies are available for only a few countries. The **United Kingdom** has been the subject of some analysis by the Institute for Fiscal Studies (see PEARSON/SMITH(1990) and JOHNSON/McKAY/SMITH(1990)). This analysis has shown two main results that are of importance when devising a tax policy to reduce CO_2 emissions:

- First, it confirmed the hypothesis that the share of income spent on energy decreases with the level of income. Thus, while households of the lowest income decile spent around 13% of their gross income on energy, the figure is only close to 3% for those belonging to the highest ten percent of the income pyramid (see table 11).

- Second, it illustrated that the share of the different fuel types used by the different income groups is far from uniform. This is of particular importance for the evaluation of the effects of introducing a carbon tax. In the United Kingdom, for example, over 70% of the households of the highest income decile use gas central heating (which would only be subject to a low carbon tax rate), while the same share is only 30% for the lowest income group.

On the basis of these observations, there is the presumption that a carbon tax is likely to be somewhat regressive as far as domestic energy use is concerned. Preliminary results from an analysis undertaken by SYMONS/PROOPS/GRAY(1991) even indicate that the negative impact on low-income households in the United Kingdom could be significant.

With respect to the **United States**, two studies investigated the impact of the introduction of carbon taxes on different income groups. CHANDLER/NICHOLLS(1990) also confirmed the inequitable distribution of the tax burden among income classes. The authors note that this effect derives from a relatively high reliance on oil and electricity by lower income families and the comparatively higher tax that would be applied or passed through to these secondary energy products. They also point out different types of equity impacts arising from the specific form of compensating for the undesired distributional effects of carbon taxes (e.g. earned-income tax refunds, redistribution through the welfare system, per-capita rebate of the tax revenues, rebate of corporate income taxes).

POTERBA(1990), on the other hand, has recently looked more closely at the issue of carbon tax regressivity. Although he also finds a high degree of regressivity when using consumer income surveys, the regressivity is much smaller when the comparison is based on household expenditure surveys. Poterba's argument is, in fact, that a household's annual income may be an unreliable indicator of its actual well-being, as income may vary significantly from year to year while expenditure is more predictably based on life-cycle and permanent-income considerations. The empirical observations indeed seem to confirm this hypothesis (see table 12). While in terms of income a $100 per ton of carbon tax represents around 10% of the income of the lowest income decile, but only 1.5% of the highest income decile, the corresponding shares are only 3.7% and 2.3% of outlays, respectively. Thus, although these results support the view that a carbon tax may to a certain extent be regressive, the findings based on the expenditure measure of incidence are less dramatic than those based on income ranking.

A recent analysis on the basis of Norwegian data has added to this cautious evaluation of the potential regressiveness of carbon taxes (see ECONOMIC SURVEY(1991)). In fact, this study came to the conclusion that, in Norway, a carbon tax does not appear to be regressive.

Although these findings therefore constitute no fundamental objection to the use of energy or carbon taxes to reduce CO_2 emissions, they nevertheless emphasize the need to find ways of compensating possible regressive effects. A priori, this could either be done by lowering the income tax threshold or, alternatively, by paying direct income transfers. However, if the aim were to ensure that no individual household were worse off after the introduction of the tax, the compensatory expenses could possibly exceed the carbon tax receipts.

With respect to international income distribution, the effects of the imposition of a carbon or energy tax not only depend on whether the tax is introduced unilaterally or jointly, but also on how precisely such an international tax is designed. This issue will be discussed in chapter 7.1.2..

Two conclusions emerge from the above analysis of the economic effects of an emission reduction strategy based on taxation. First, although the aggregate, macroeconomic effects of such a change in relative prices appear to be small, the structural and sectoral effects are likely to be significant. These structural changes would not only occur in the private sector, but could also imply a far-reaching shift in the tax base away from labour and capital taxation, towards environment and natural resource taxation. The associated changes in the structure of public finances should not be underestimated.

TABLE 11:

DISTRIBUTIONAL ASPECTS OF CARBON TAXES IN THE UNITED KINGDOM

Decile of gross income	Fuel spending £ per week	Fuel spending as % of budget	Types of central heating: Elect. (%)	Gas (%)	Other (%)	no central heating (%)
Lowest	7.95	13.25	10.7	30.0	11.5	47.9
2.	10.05	11.40	12.3	32.6	9.6	45.4
3.	10.38	8.53	11.9	38.5	10.5	39.0
4.	11.19	6.99	11.9	38.1	12.1	37.9
5.	11.46	5.70	8.9	44.1	10.4	36.0
6.	11.21	5.25	6.8	52.5	12.6	28.1
7.	12.30	4.86	7.7	58.7	9.9	23.1
8.	12.64	4.37	6.8	61.3	12.9	19.0
9.	13.69	3.92	6.3	68.0	11.5	14.2
Highest	16.92	3.46	4.2	74.2	12.7	8.8

Source: JOHNSON / McKAY /SMITH (1990)

TABLE 12:

DISTRIBUTIONAL EFFECTS OF A $ 100 T/C CARBON TAX IN THE UNITED STATES

Distribution Across Income Classes			Distribution Across Total Expenditure Classes		
Income Decile	Total Burden	% of Income	Expenditure Decile	Total Burden	% of Outlays
Lowest	$451.9	10.1%	Lowest	$252.5	3.7%
2.	374.6	5.0	2.	349.8	3.7
3.	484.6	4.6	3.	465.6	3.8
4.	521.0	4.1	4.	527.5	3.7
5.	563.7	3.6	5.	588.6	3.4
6.	608.6	3.0	6.	681.3	3.4
7.	689.6	2.7	7.	772.3	3.2
8.	762.6	2.3	8.	804.2	2.8
9.	875.3	2.1	9.	944.2	2.7
Highest	889.7	1.5	Highest:	871.4	2.3

Source: *POTERBA (1990)*

5.2.3. How can the different results be explained?

The above discussion of the presently available studies evaluating the use of taxes as instruments to reduce CO_2 emissions has revealed a certain degree of divergence concerning the size of the required tax rates (see also table 6). The question therefore arises of how these differences can be explained. Eight main categories of factors have to be distinguished:

(a) Assumptions concerning baseline emissions

For those studies analyzing the costs of future emission reductions by reference to the amount of emissions in a certain reference year in the past (e.g. 1987), the tax rate required to achieve a given reduction target obviously depends on the trend of emissions without policy measures (baseline, business-as-usual or conventional-wisdom scenario), i.e. implicitly on the assumed future trends in GDP, population, energy prices, technologies etc.. As can be seen in table 3 and graph 5, these baseline forecasts differ significantly between Community Member States, indicating that, for this reason alone, the efforts required to reduce emissions by a given percentage compared to a base-year in the past are likely to diverge strongly.

The important role of the baseline has been forcefully illustrated by a study undertaken by the US Congressional Budget Office (CBO(1990)) which compares the results of a simulation with the Edmonds-Reilly model with a comparable simulation undertaken by Manne and Richels. While in the Edmonds-Reilly model simulation, a \$100 tax is sufficient to reduce US carbon dioxide emissions in the year 2100 by 20% compared to the present level, Manne and Richels calculate a tax rate of \$250 to reach the same target. One of the main reasons for this dramatic difference lies in the fact that the Edmonds-Reilly baseline emissions for the US in 2100 amount to 8.2 billion tons whereas the Manne-Richels emissions exceed 10 billion tons. (Incidentally, the differences with respect to the worldwide emissions in 2100 are even larger: Edmonds and Reilly assume 22.6 billion tons versus 42.6 billion in the Manne-Richels baseline).

(b) The choice of the model parameters

The analysis of the different simulation exercises presented above reveal that there are mainly three sets of crucial parameters:

- First, elasticities. This concerns (own) price elasticities of energy demand, (cross-price) substitution elasticities between different types of fuels and between energy and other production factors and income elasticities of energy demand. Ceteris paribus, the higher the price elasticity, the lower the tax rate has to be to reach a given emission reduction target. Table 7 gives some indication of the range of elasticities normally found in the literature. On the other hand, the lower the cross price elasticities between different types of fossil fuel and the higher the cross price elasticities between energy and other production factors, the higher is the emission reduction effect of a carbon tax with any given own price elasticity of one type of fossil fuel. Thus, for a full evaluation of the power of a tax, the entire set of elasticities has to be considered. It has to be emphasized in this context that a small change in just one elasticity of the entire set of elasticities can significantly affect the power of a carbon/energy tax (see BARRETT(1990c) for details).

  BURNIAUX/MARTIN/NICOLETTI/MARTINS(1991) have evaluated the sensitivity of the GREEN model simulation results to changes in certain key elasticities. By changing the inter-energy substitution elasticity, for example, from 1.2 in the baseline to 2.0 and by raising the supply elasticity of "carbon-free" energy sources from 0.2 to 0.5, the tax rate required to reach a Toronto-type of emission target is cut by half ($109 instead of $215).

Concerning the income elasticities of energy demand, both macroeconomic and microeconomic aspects have to be considered. At the macroeconomic level, the policy objective is to decouple economic growth and energy demand. Thus, an income elasticity of zero is aimed at. At the microeconomic level, on the other hand, certain energy consuming economic activities can have high income elasticities. A case in question is private individual road transport. Past experience has shown, in fact, that the income effect can sometimes even be so high as to overcompensate the fall in energy demand stemming from energy efficiency improvements.

- Second, exogenous (energy saving) technological progress. Analysis of the above mentioned study by MANNE and RICHELS (1991), for example, reveals that the strong increase in future energy demand is largely due to the assumed low rate of autonomous (i.e. not price-induced) energy efficiency improvement (AEEI)[21]. If, as some authors (e.g. WILLIAMS (1990)) argue, the rate assumed by Manne and Richels (0.5 per year for the OECD countries) is extraordinarily low, then the carbon tax rate that would be required to reach a given reduction target could be far lower that the calculated $250. To illustrate the crucial importance of the assumed rate of autonomous energy efficiency improvement, Williams has calculated that assuming a rate 1 percentage point higher than Manne and Richels would result in an energy demand at the end of the 21st century of only 1/3 of the corresponding Manne/Richels estimate.

  Responding to the criticism by Robert Williams, MANNE and RICHELS(1990b) have simulated alternative parameter values for AEEI (ranging from 0 to 1.5 p.a.). In the extreme case of an annual improvement in energy "efficiency" of 1.5, the energy requirements by the end of the next century would only be 20% of the AEEI=0 scenario. Consequently, the required carbon tax rate and therefore the economic costs differ significantly between these two extreme cases. The crucial role of this parameter has also be confirmed by sensitivity tests with the OECD's GREEN model (see BURNIAUX/MARTIN/NICOLETTI/MARTINS(1991)). The result of these tests was that halving the rate of autonomous energy efficiency improvement from 1% p.a. to 0.5% p.a. almost doubles the carbon tax rate needed to attain the emission reduction target ($401 instead of $215).

- Third, available technologies. Again, it is useful to illustrate this point using the MANNE/RICHELS study. Using the same formula, WILLIAMS(1990) has calculated an equilibrium carbon tax rate of only $59 (1/4 of the MANNE and RICHELS figure), by adopting different assumptions (based on existing but not yet commercially available technologies) concerning the future cost of producing methanol from coal and biomass. In general, these assumptions concerning technologies (e.g. with respect to renewable energy sources) become more important (and, in view of the existing uncertainty, also more debatable), the further the analysis reaches into the future. This is of particular relevance with respect to the issue of backstop technologies.

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21 BOERO/CLARKE/WINTERS(1991) have recently criticised the use of this expression as, in the Manne-Richels model, the parameter is defined as energy demand per unit of output and therefore not only captures technical progress, but also changes in the sectoral composition of output, i.e. changes in energy intensity.

(c) The revenue use

The importance of the type of tax revenue use for determining the economic impact of the introduction of a carbon/energy tax has already been stressed in sections 5.1.2.(a) and 5.2.2(a). In particular, the crucial role of whether the tax revenues are recycled to the economy or not has generally been confirmed. As to the precise way of revenue recycling, no unequivocal picture emerges from the available studies. While generally a reduction in labour taxes (notably employer's social security contributions) appears to result in comparatively favourable economic effects (see e.g. DETEMMERMAN/DONNI/ ZAGAME(1991) and BRINNER/SHELBY/ YANCHAR/CRISTOFARO(1991)), no such consensus appears to exist as to the precise effects of a reduction in income taxes. This may either be due to differences in the specifications of the econometric models used, or it may reflect the specific situation of the country under investigation. Further research is required to shed some light on this issue.

(d) Non-linearities

Economic analysis suggests that the marginal costs of CO_2 emission reduction rise with the abatement level. Thus, the more ambitious the abatement level, the higher the costs per ton of carbon not emitted. Although few models have been used for explicitly analysing this issue, the analysis undertaken by BERGMAN(1990) on the basis of a general equilibrium model for Sweden clearly illustrates these non-linearities in terms of the tax rate required to reach different abatement levels (see table 6). Other models come to similar conclusions.

(e) Joint versus isolated action

For the macroeconomic effects of tax policies to reduce energy related CO_2 emissions, it may be of importance whether the carbon or energy tax is introduced in an isolated way or simultaneously by all the main competitors. If the introduction of the national tax leads to an increase in the costs of production, this country's products would - at least in the short-run and ceteris paribus - be less competitive on world markets with the corresponding repercussions on trade balance and domestic production. The higher the energy intensity of production, the more this will be so. If, on the other hand, all competitors introduce a carbon tax, or if the average tax burden remains unchanged, then there is no general negative competitiveness effect. Nevertheless, countries with a comparatively energy intensive production pattern will be faced with a structural reduction in demand.

With respect to the quantitative evaluation of the differences between joint and isolated action, preliminary simulations with the HERMES model seem to suggest that these differences appear to be relatively small (e.g. of the order of 0.1% of GDP after five years), both for revenue neutral and revenue raising taxes. It is interesting to note, in this context, that coordination generally appears to amplify the macroeconomic effects of the measures, either in the negative sense (in the scenario without redistribution of the tax revenues) or in the positive sense (revenue neutral tax). The main reason for this phenomenon is the fact that (at least in HERMES) the income effect dominates the competitiveness effect. Thus, if the introduction of a carbon tax leads to GDP losses (compared to the reference scenario), export demand may actually, depending on the respective elasticities, be higher if the major trade partners do not follow this policy.

Nevertheless, joint action is, of course, desirable for several reasons. Firstly, the purpose of introducing a carbon tax is to slow down global climate change. It is evident that no individual country can achieve this task on its own. It is, therefore, not surprising to find that studies investigating the effects of unilateral action, for example by the European Community, come to the conclusion that such action, although economically harmless overall, would also be environmentally ineffective (see e.g. PEZZEY(1991)). Secondly, as has been discussed in the context of the sectoral effects, the unilateral introduction of a carbon/energy tax can be expected to imply a much stronger impact on the sectoral composition of output than a unilateral tax (see table 10). To the extent that the unilateral introduction of a carbon/energy tax leads to a dislocation of industries, the economic costs incurred by the country introducing the tax are not even matched by corresponding environmental benefits.

One aspect that has been the subject of comparatively little modelling analysis to date is the likely impact of joint action on world market prices for oil and natural gas. As a multilateral tax would have a much stronger impact on (aggregate) world fossil fuel demand than a unilateral tax, world market prices for energy could be expected to fall, thereby both the economic and the environmental impact of the tax (see e.g. CBO(1990)).

(f) The timing

Although there are both theoretical and empirical reasons for arguing that the timing of (tax) policies to reduce greenhouse gas emissions is very important, few studies have attached great importance to this question and systematically analyzed different possible time paths. The notion of timing used here is a broad one, encompassing at the same time the size of changes and the predictability of changes. Thus, the argument is that different assumptions concerning the time profile of taxes and the way these tax changes are anticipated and perceived can explain part of the differences found in terms of the economic effects.

From a theoretical point of view, the atmosphere can be considered as a natural resource among others (exhaustible or renewable) that serve as "inputs" in the production process. Its "optimal" rate of depletion can therefore be analyzed using the corresponding theoretical tools (see e.g. NORDHAUS(1982) and DEUTSCHER BUNDESTAG(1990b)). Applying this framework, most analysts come to the conclusion that the carbon tax rate would have to rise over time. SINCLAIR(1990) has argued, however, that when taking into account fossil fuel supply behaviour, expectations of falling energy taxes are what are needed to reduce extraction rates and thereby to postpone CO_2 emissions. Generally, the higher the potential demand for emissions due to economic and population growth, the higher the tax rate has to be to respect an upper limit on the atmospheric concentration of CO_2.

From the empirical point of view, JORGENSON and WILCOXEN (1990a) have calculated in their study on the effects of energy prices on the US economy that approximately two thirds of the GDP losses they ascribe to the historical development of oil prices since 1972 are due to the price shocks and only the remaining third is due to the price rise. In addition, a second aspect to be considered is the issues of retrofitting and accelerated scrapping. As in some areas, e.g. the building sector, it is up to ten times more expensive to reduce energy consumption by retrofitting than by using the corresponding technologies in the initial construction, a gradual implementation of such measures is bound to be considerably less costly compared to a sudden implementation. It should be mentioned in this context that it is also easier to implement new technologies in periods of economic growth compared to periods of stagnation.

In the business sector, on the other hand, the profitability of investments depends, among other things, on whether the expected economic life-time is realized. If suddenly, by virtue of the introduction of a high energy/carbon tax, the existing production equipment becomes economically obsolete although it had not yet reached the end of its life, this constitutes a high (private) cost to the company ("sunk cost"). If, instead, the future tax increase is known in advance and therefore integrated into the calculus of the investment decision, no such adjustment costs of accelerated scrapping occur.

Analogously, a similar argument holds for the household sector. Households buy durable consumer goods on the basis of an expected length of life of the product. The life-time of the product in turn determines the turn-over in the stock of equipment. Unexpected price changes either lead to premature obsolescence and therefore represent a welfare loss for consumers, or they are largely ineffective due to the low turnover in the stock of equipment.

Moreover, there is one additional argument in favour of predictable policies: contrary to 'surprise policies', they allow the supply side to adjust to the new situation. To give an example, if energy prices were suddenly to triple, existing consumer as well as producer goods would be economically inefficient. However, as the design and production of new energy efficient products takes time, private economic agents would in effect be unable to immediately adjust their stock of equipment, even if they wished to do so.

For the above mentioned reasons, one could tentatively conclude for the design of greenhouse gas policies that the "optimal" time profile of a carbon tax is likely to consist of an initial tax rate that is significant enough to change energy users' behaviour, but low enough to avoid major economic disruptions and high adjustment costs. The tax rate should then gradually and predictably rise, in order to create stable <u>expectations</u> by signalling to market participants an increasing scarcity of natural resources.

(g) The type of model used

As has been set out in section 5.2.1., different types of models are used to study carbon/energy tax policies. However, the model choice to some extent also influences the simulation results. In general, computable general equilibrium models assume a much higher degree of flexibility than traditional, partial equilibrium macroeconometric models. A greater degree of flexibility, in turn, implies lower costs of CO_2 emission reduction. The importance of this factor becomes apparent when looking at table 6 and comparing the results obtained by the JORGENSON/WILCOXEN(1990b) general equilibrium model with the results from the DRI macroeconometric model (CBO(1990)).

(h) Country specificities

Most multi-country or multi-region model simulations clearly bring out the important role of national or regional specificities. Thus, factors like the composition of the domestic fossil fuel base, the industrial structure of the economy, past efforts in terms of energy efficiency etc. imply that the effort needed in order to reduce emissions by a certain amount varies considerably between countries or regions. This phenomenon can be illustrated by reference to a simulation exercise undertaken by Alan MANNE(1991) using the GLOBAL 2100 model and simulating a "comparable effort" in reducing emissions compared to the (regional) baseline. This analysis, assuming a reduction in the annual growth rate of CO_2 emissions by 2% compared to the emission growth in the baseline, reveals that significantly different tax rates are required in different world regions, i.e. that the marginal abatement costs vary considerably (see table 13).

TABLE 13:			
CARBON TAX RATE REQUIRED TO REDUCE THE ANNUAL GROWTH RATE OF CO_2 EMISSIONS BY 2% COMPARED TO THE GROWTH RATE IN THE BASELINE (US $ / t c)			
	2000	2020	2040
USA	135.4	299.4	224.5
Other OECD	135.4	244.0	208.9
USSR	135.4	277.2	754.1
CHINA	257.0	154.9	219.1
REST OF THE WORLD	227.8	293.8	552.4
Source: *MANNE (1991)*			

5.3. Addressing the issue by choosing the "bottom-up" approach: identifying the emission reduction potential

The above discussion of the available studies applying the "top-down" approach to the issue of CO_2 emission reductions has not only highlighted the potential efficiency of the price mechanism in bringing about emission reductions, but also the limitations of such an approach. Several studies have come to the result that - at least in the short-run - taxes alone will not allow ambitious emission reduction targets to be reached, unless very high tax rates (several hundred percent of present energy prices) are applied. By definition, the price mechanism can only be an optimal policy instrument if there is a functioning market. However, in situations of market failure or even market inexistence, other policy instruments are more efficient. It is undisputed that such market imperfections exist in the context of the energy related emission of greenhouse gases. The "bottom-up" approach attempts to identify these areas and to design the appropriate policy instruments for exploiting the corresponding emission reduction potential. The "bottom-up" approach therefore takes a more micro-economic point of view, based on detailed technological and engineering information. By aggregating the costs associated with the measures to exploit the available emission reduction potential, an aggregate emission reduction cost curve can be established which can then be used for deciding upon an aggregate emission reduction target.

Before identifying the available CO_2 emission reduction or energy saving potential, it is necessary to briefly define the notion of "potential". In fact, five different types of emission reduction potential can be distinguished (see also graph 12):

- the **theoretical potential** defines the limit to the reduction of emissions set by the laws of physics (as known to us);

- the **technical potential** defines the amount of emission reduction that could be obtained with presently available technologies;

- the **socially profitable potential** specifies the amount of emission reduction that would be economically viable from the point of view of society;

- the **privately profitable potential** is smaller than the socially profitable potential where market prices do not reflect the full cost of using fossil fuels;

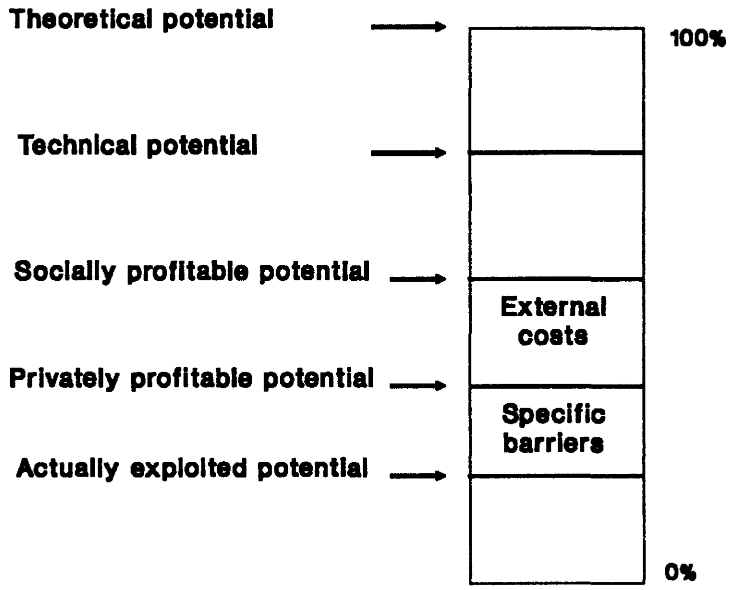
- the **actually achievable potential,** finally, represents what can be realistically expected to be achievable when taking into account transition lags, imperfections etc.;

In order to be comprehensive, the "bottom-up" approach does not only have to cover all sectors of economic activity, but also all available technologies and all available instruments. Otherwise important energy conservation potentials might be missed. Thus, there is an enormous amount of information that has to be processed. Concerning the mechanisms by which an energy-related emission reduction could be attained, three main classes can be distinguished analytically:

(i) energy conservation through increased energy efficiency (end use and conversion);
(ii) substitution between different types of fuels;
(iii) reduced level of energy services[22]

[22] This option will not be treated in the present note for the following reasons: Undoubtedly, energy co... be saved if vehicle drivers reduced their maximum speed on the motorway, if average ro...

GRAPH 12: TYPES OF ENERGY SAVING POTENTIAL
(Purely illustrative)



5.3.1. The energy efficiency potential

The starting point for any discussion of the potential for energy efficiency is the following. Individual economic agents, households as well as companies, use energy in order to benefit from the services it provides (e.g. warming up or lighting a room, transporting a good etc.). However, only about one third of the primary energy input is actually available as useful energy providing the energy services. The rest is lost in different stages of the conversion process. The aim of improving energy efficiency or rational energy use is therefore to provide the same energy services with a reduced amount of primary energy input.

(a) What is the potential?

Ideally, the assessment of the economic potential for reducing energy-related CO_2 emissions in different economic sectors should be based on sectoral emission reduction cost curves. In practical terms, however, most studies only focus on the potential evaluated on the basis of "current prices". Thus, the following discussion will only give "point estimates" for the potential in different sectors, rather than cost curves allowing the determination of the economic emission reduction potential as a function of energy prices.

One of the most important, economical emission reduction potential is considered to exist in the **household or residential sector**. This includes, on the one hand, the potential of

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temperatures were lowered etc.. However, this would require a change in people's preferences which cannot, as already explained in section 3.1., be the scope of economic analysis.

electricity saving associated with lighting (e.g. through the switch to fluorescent light bulbs) or household appliances (more efficient refrigerators, washing machines etc.). On the other hand, it covers the large potential of improving energy efficiency in the domain of room and water heating. It is generally recognized that the technical potential for improving energy efficiency (and therefore for reducing CO_2 emissions) is very large in this sector. In particular with respect to space heating, the emission reduction potential is estimated to be between 50% (DEPARTMENT OF ENERGY(1989)) and 90% (DEUTSCHER BUNDESTAG(1990b)). Many of the required measures (notably roof and wall insulation) have short payback periods, even in the case of retrofitting (see e.g. SKEA(1990)). The same is true for the areas of hot water boilers, lighting and electricity use by household appliances. Only double glazing requires a longer payback period.

On the other hand, the residential sector is characterized by a comparatively low turn-over in the stock of buildings. Thus, within the next 10-20 years the main contribution to energy saving will have to come from retrofitting. Taking all these aspects together, it would appear to be reasonable to conclude that measures to promote energy saving in the residential sector could help to reduce overall CO_2 emissions by about 6% in the next 10-20 years without incurring significant net economic costs (see e.g. COMMISSION(1990b)).

There is also an important energy efficiency potential in **industry**, probably close to or perhaps slightly smaller than the potential in the domestic sector. One major mechanism by which energy efficiency could be increased significantly is the combined on-site generation of heat and power (CHP). In addition, efficiency improvements in space heating (insulation), water heating (more efficient boilers) and process heat as well as a better use of residual heat are of some importance.

Concerning the **service sector** (market and non-market), the characteristics appear to be between those in the domestic and in the industrial sector. While the largest energy saving potential can be identified in the field of (space or water) heating and electricity use as in the domestic sector, the decision-making process with respect to energy efficiency measures resembles more that observed in industry.

The **transport sector** represents one of the most difficult sectors of economic activity to deal with in the context of policies to reduce greenhouse gas emissions. On the one hand, the technical CO_2 emission reduction potential is evaluated to be of the order of 50-60% of present emissions (see DEUTSCHER BUNDESTAG(1990b)). In addition, the existence of significant external costs of road transport implies that private road transport (in particular heavy goods transport) is heavily underpriced thereby driving a wedge between privately and socially profitable emission reduction measures.

On the other hand, the experiences of the past have revealed the difficulties of reducing emissions from cars. Not only were the improvements in energy efficiency overcompensated by a higher demand for road transport services and more powerful cars, but also all the evidence points towards very low price elasticities of the demand for private individual transport. The situation is aggravated by the fact that future CO_2 emissions stemming from the transport sector are forecast to increase markedly in response to increased economic integration (especially in response to the developments in Central and Eastern Europe and the creation of the Internal Market; see e.g. TASK FORCE(1989)) and higher incomes[23]. Overall, therefore, tax rates would have to be very high in order to result in significant emission reductions. (It should be mentioned, though, that this analysis neglects a possible supply side response on the part of car producers.) It needs to be kept in

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[23] The high income elasticity of private individual transport is likely to present a special problem in developing countries where aspirations are high and car ownership is far from reaching saturation levels.

mind, however, that the efficiency requirement implies that (carbon) tax rates should be equal for all types of fossil fuel use. Thus, from the economic point of view, it does not matter where consumers decide to reduce emissions and where they prefer to pay the tax instead.

The analysis of the likely causes of the observed low response to price changes (i.e. of the apparent difficulty in exploiting the energy efficiency potential) reveals two major issues of importance. First, the difficulty of attaining a significant shift in the mode of transport from private vehicles to public transport can be due to an insufficiency in the available supply of public transport services. Second, it can be the result of the prevailing structure of individual preferences, which gives a high weight to individual mobility and powerful engines. As argued above, it cannot be the economist's task to change preferences. It is, however, the economist's task to ensure that the price of road transport paid by the user reflects the full cost of this mode of transport. This can be achieved by different types of taxes (e.g. fuel taxes or vehicle taxes differentiated depending on the degree of fuel efficiency) or other specific measures. Aiming at an emission reduction beyond this socially optimal point (e.g. by forcing citizens to use public transport) implies welfare losses and is therefore economically inefficient.

In the **energy sector**, finally, the potential for improving energy efficiency not only concerns the end use, but most importantly the conversion of energy. In the field of electricity generation, new technologies (like, for example, integrated gasification combined cycles or fluidised bed combustion for coal) could increase the conversion efficiency by over 10 percentage points (see e.g. COMMISSION(1987), SKEA(1990) and the preliminary results of the Community's JOULE programme). In addition, there could be some scope for reducing losses in energy distribution. It should be noted in this context, that inefficiencies are markedly higher in Eastern Europe (incl. USSR) and the Third World (see chapter 7).

(b) Why is the energy efficiency potential currently not exploited?

The above analysis has shown that there is a significant potential for reducing energy related CO_2 emissions that appears to be economically viable not only from the point of view of society, but often even when seen from the standpoint of the private economic agent, i.e. when using present market prices.[24] The question therefore arises of why this apparent potential is currently not exploited.

The main reasons for this failure to exploit the full, apparently economical energy efficiency potential are associated with market failure and institutional impediments. The major causes are the following:

(i) Lack of information and (hidden) transaction cost: there is little disagreement concerning the fact that consumers in particular are far from being the fully informed economic subjects of economic theory. Thus, often buyers are unaware of the fact that they could reach their aim at less cost and energy users are either unaware of the amount of energy wasted or lack the technical knowledge for reducing this inefficiency. This is particularly the case for private households and small-sized companies (see e.g. JOCHEM/GRUBER(1990)). (For example, consumers usually fail to recognize the economic advantages of fluorescent light bulbs compared to the traditional incandescent lamps.) However, from the individual point of

[24] This importance is also reflected in the Community's energy policy. See for example the 1987 Communication on energy efficiency (COMMISSION(1987)) and the recently adopted SAVE programme.

view, it might be costly to search for the corresponding information. If the monetary gains from energy saving amount only to a small absolute amount per year, it would be 'irrational' for the consumer to invest time and money in the search for the necessary information. It is, therefore, difficult to decide a priori whether such investments would be profitable or not from the individual point of view. It is nevertheless clear that they would be profitable from the point of view of society.

(ii) Purchaser is not the user: this can be easily illustrated by taking the example of rented accommodation. If the house owner is not the occupier, he has an economic interest in keeping the investment cost low, as the correspondingly higher running costs are borne by the tenant. The tenant, on the other hand has no interest in undertaking energy saving investments as they would go over into the property of the house owner when the tenant moves out of his apartment. Thus, the separation between the expenditure in energy conservation and the benefit from such a conservation can constitute a powerful barrier against energy saving investments.

(iii) Discount rate differences: it is well known that consumers tend to have extremely high discount rates, ranging between 30% and 200% per annum (see e.g. the references in BARRETT(1990c)). This means that they require 'investments' in energy saving to have a pay-back period that rarely exceeds three years and sometimes not even reaches one year. On the other hand, the social discount rate for investments is usually evaluated to be in the order on 5% p.a.. Thus there is an enormous potential for energy saving in the household sector that would not only be profitable from the point of view of society, but even from the point of view of other market participants. However, institutional and behavioural barriers presently impede the exploitation of this potential.

(iv) Capital constraints: especially in the case of low-income households, capital constraints can impair energy conservation investments, as these households neither own the required capital themselves nor would it be easy for them to get the corresponding bank credits. From the point of view of the energy system, on the other hand, it could be argued that reliance on large-scale energy supply technologies (such as for example nuclear) leaves less financial resources for either alternative, decentralized small-scale technologies or energy saving measures.

(v) Supply strategies: several aspects are of importance in this context. First, the price structure adopted by electricity suppliers frequently does not give an incentive for energy saving (e.g. by giving rebates to large-scale users). Often, notably in many developing countries, energy prices are lower than the long-run marginal cost of energy supply. Second, electricity and gas utilities themselves normally lack economic incentives to encourage energy conservation (see the next section). They also lack incentives to allow independent sources of electricity supply (e.g. from cogeneration in industry) access to their distribution grid. Third, suppliers of energy consuming goods rarely have marketing strategies focusing on the aspect of energy efficiency.

(c) What can be done to exploit the potential?

For the discussion of the policy options that exist for exploiting the available emission reduction potential, it is useful to take up the distinction between the different types of reduction potentials set out above. Generally speaking, the dispersed character of the emission reduction opportunities renders public action more difficult and requires a carefully designed package of different measures.

The <u>first question</u> is: how can the existing energy efficiency (and therefore CO_2 emission reduction) potential be used which already appears to be <u>profitable at current market prices</u>, but is not yet exploited?

(i) A first class of measures designed to exploit the privately profitable potential of energy efficiency gains uses more traditional policy instruments. Two main instrument sets are of importance:

- <u>economic measures to improve penetration rates</u>: on the basis of the above discussion, two main mechanisms could be considered. On the one hand, direct financial assistance to low income households for energy saving measures (e.g. grants, tax rebates, "soft loans" etc.). On the other hand, fiscal incentives to substitute energy efficient equipment for energy inefficient equipment. However, experience has shown that such financial support measures are often less cost-effective than other policy measures, for example due to important free-rider effects (see JOCHEM/GRUBER) or high administrative costs.

- <u>improving information</u>: as has been seen, not only consumers are often unaware of the profitable scope for improving energy efficiency. One relatively easily applicable and cheap way to improve consumers' information is the introduction of <u>energy efficiency labelling</u>. Such labels would not only drastically reduce the energy conscious consumer's transaction cost, but could also serve prominently in new marketing strategies. Other information improvement measures relate to education and professional training. A further (information improving) instrument that frequently attains even higher benefit-cost ratios than investment subsidies is the subsidisation of <u>energy efficiency consulting</u>.

- <u>voluntary agreements with producers</u>: if the number of producers of certain types of fossil fuel using equipment is small, voluntary agreements between the government and the producers can in some cases be preferable to traditional regulations. Not only are the administrative costs likely to be smaller, but the flexibility is also in general higher.

(ii) A second class of measures relates to what has been called regulatory/institutional reform to install or enhance the market mechanism (see section 5.1.3.). It consists of measures called least-cost planning, third party financing, contracts for energy management etc..

<u>Least-cost or integrated resource planning</u> is a practice that has mainly been developed for the utility sector in the United States. The basic idea of least-cost planning starts from the observation that in most countries utilities in the electricity and gas sector are regulated in a way that more or less allows them to determine prices by adding a mark-up on costs. Thus, profits grow with the volume of sales, thereby constituting a disincentive to promote energy saving.

The fundamental principle of least-cost planning is to change the regulatory framework applying to publicly controlled utilities in the sense that these companies no longer see their main purpose as supplying energy, but rather as supplying <u>energy services</u>. Thus, as already set out above, the basic premise is that the utilities' customers are interested in energy services and not energy for its own sake. The instrument to implement these changes is to require utilities to explicitly compare the costs of investing in additional supply capacity with the costs of energy efficiency investments (see e.g. BROWN(1990)). If it is cheaper to meet the additional demand for energy services by investing in energy efficiency than by investing in additional supply capacity, least-cost planning requires utilities to opt for energy efficiency (so-called demand side management).[25]

The experience made with this "traditional" approach to least-cost planning has recently led to the discussion of several refinements and extensions:

- One of the main short-comings of the "traditional" regulatory approach to least-cost planning is that it requires utilities to undertake least-cost planning without, however, offering them an economic incentive for doing so. As a result, utilities tend to pay attention to energy conservation measures only when faced with supply (expansion) constraints. In the present context of significant over-capacity in the electricity generation sector in the Community, utilities have no economic incentive to promote energy saving. In order to remedy this problem, attempts are now being made (in the United States) to <u>reform utility regulation</u> so as to ensure that a utility's least-cost plan - including the promotion of energy conservation - is at least as profitable as other courses of action for the utility, namely the expansion of the technical supply capacity. This is done by allowing the utility to keep part of the money that is saved by energy conservation measures as a return on such measures.

- Among ideas to extend and improve least-cost planning, the concept of <u>"all-sources-bidding"</u> figures prominently. Again, the underlying idea is fairly straightforward (see e.g. LOWINS(1989)): assume, for example, an electrical utility (which can also be the distribution company in a vertically disintegrated energy market!) is faced with an expected demand increase. This utility could call for bids to meet this additional demand. On the one hand, an electricity generating company can offer to supply the required amount of electricity at a price that reflects the costs of installing the additional supply capacity. On the other hand, private companies (see the next paragraph) could offer to undertake electricity conservation measures that would save the same amount of electricity (these companies would offer 'saved megawatts', so-called "n"egawatts). The electrical utility would accept the bid that has the lowest cost per kw/h, independently of whether it is "generated" by supply-side or by demand-side measures. Moreover, such a bidding procedure could also be used for integrating environmental concerns. This could be done, for example, by regulating the bidding procedure such as to multiply the offered bid price by a coefficient reflecting the external (environmental) costs of the offered energy (e.g. on the basis of a specified set of characteristics). Attempts to install such a "full (social) cost dispatching" are currently under way in the United States.

- Linked to the question of how the existing energy efficiency potential could be exploited is also the concept of <u>third party financing</u> or <u>contract energy</u>

[25] The importance of these cost differences can be illustrated by reference to those experienced in the United States. The utility company NEW ENGLAND ELECTRIC(1989), for example, has compared the cost-effectiveness of energy efficiency versus power supply alternatives. The result of this comparison showed that efficiency measures were approximately twice as cost-effective as the installation of new gas turbines.

management. The basic idea of such a scheme is to allow specialized private companies with the required capital and technical expertise to exploit the economic potential for energy conservation that is presently not used either due to market imperfections or due to institutional barriers (for details see e.g. ASSOCIATION(1988)).

The second question concerning ways to exploit the available energy efficiency potential is: what can be done to eliminate or reduce the gap between the privately profitable and the socially profitable emission reduction potential? Two, not necessarily mutually exclusive, options are available:

(i) The economically most appealing way is to ensure that the prices which form the basis for the economic calculus of private economic agents reflect all social costs. This implies that the social costs of fossil fuel use are internalized into market prices. It is clearly here that the policy instruments discussed in the above section on the "top-down" approach, in particular taxes and charges, have their comparative advantage, both in static and in dynamic terms (e.g. in directing private R&D efforts).

At the same time, such an internalization of the social cost of fossil fuel use would not only increase the economic potential for energy conservation measures in the private sector, but it could also encourage the exploitation of the existing potential by increasing the financial incentive and thereby overcoming possible thresholds of perception.

(ii) In cases where such a recourse to the market mechanism is impossible, the public sector should either undertake the corresponding emission reduction measures or rely on the traditional regulatory instruments.

The third question, finally, is: what can be done to narrow the gap between the theoretical and the socially profitable emission reduction potential? Evidently, in static terms there is no economic justification to take measures to close the gap. In dynamic terms, however, it is important that the public sector's investment decisions are based on the expected social rate of return. In this context, public financial support for basic research and development of energy efficient technologies can have a significant role to play.

5.3.2. The fuel substitution potential

(a) What is the potential?

In order to evaluate the greenhouse gas emission reduction potential stemming from fuel substitution, it is necessary to distinguish the two classes of substitution possibilities:

(i) Substitution between fossil fuels

As illustrated in table 4, coal has a carbon emission factor approximately 70% higher than the emission factor for natural gas and almost 30% higher than the emission factor for crude oil. A substitution of coal (and to a lesser extent of oil) by natural gas could therefore reduce CO_2 emissions without requiring a reduction in overall energy use. Evidently, the potential is highest in those countries where the share of coal in total energy is at present comparatively high. For Germany, for example, the technical potential of CO_2 emission reductions through fuel substitution is estimated to be of the order of 20% of present CO_2 emissions (see DEUTSCHER BUNDESTAG(1990b)).

For the Community as a whole, the potential scope for fossil fuel substitution as an option for reducing emissions can be illustrated by the following rough calculation (see COMMISSION(1990b)). The present fossil fuel-mix used in European power stations is 67% coal and lignite, 16.5% petroleum, 11% natural gas and 5.5% other fuels. If, in a kind of "thought-experiment", the respective shares of gas and coal were interchanged, i.e. if the share of gas were 67% and the share of coal 11%, then carbon emissions by the power generation sector would be approximately 29% lower.

However, several factors complicate the precise economic evaluation of the fossil fuel substitution potential.

- First, the size of the economic potential depends on the coal prices used for the evaluation. While on the basis of the high European coal prices the economic potential for fossil fuel substitution is considerable, such a substitution would be costly when judged on the basis of the low world market prices for coal.

- Second, in the case where there would be a worldwide shift towards natural gas, world gas prices could be expected to rise. Moreover, a strategy relying on a large-scale shift towards natural gas could in certain cases imply adverse effects on a specific country's energy supply security.

- Third, coal reserves constitute by far the largest share of total fossil fuel reserves. This is particularly important for countries like the United States and China. A shift towards natural gas would require these countries to import gas instead of using domestic coal.

- Fourth, in the context of a possible large-scale substitution of coal by natural gas, it is again necessary to adopt a more comprehensive approach considering all greenhouse gases. The issue at stake here is methane emissions. Two independent aspects have to be taken into account. On the one hand, coal mining contributes significantly to methane emissions. (In the Federal Republic of Germany, for example, coal mining is responsible for over 40% of methane emissions.) On the other hand, natural gas usually consists to at least 90% of methane. Any leakages in the production or transport of natural gas would therefore tend partly to offset the gains in terms of radiative forcing achieved through a reduction of CO_2 emissions by increased methane emissions (remember that the global warming effect of one molecule of methane is about twenty times as high as for one molecule of carbon dioxide). There is, however, broad agreement that this effect is not important enough to fully compensate for the gains from reducing CO_2 emissions, in particular when taking into account the shorter life-times of methane molecules in the atmosphere.

(ii) Substitution between fossil and non-fossil fuels

Renewable energy sources (e.g. hydropower, geothermal, solar, wind, biomass, hydrogen) have an important role to play in a strategy against global warming. Although some amount of CO_2 is emitted in the production process of the equipment required for using renewable energy sources, the (sustainable) use of these sources themselves does not increase net CO_2 emissions (even in the case of biomass, the CO_2 released in the combustion process has previously been absorbed by the plants during their growth phase). In addition, the available technical potential of renewable energy sources is practically unlimited.

The detailed economic potential for using renewable energy sources, on the other hand, is difficult to quantify. First, this potential is highly location specific (for example duration and intensity of sunshine, wind etc.). Second, concerning the future potential, much depends not only on fossil fuel prices, but in particular on the pace of technical progress in this field. Generally speaking, the cost of renewable energy sources are decreasing with time (for some promising technologies even rapidly), while the cost of fossil fuel is forecast to rise. Thus, the precise point in time at which renewable energy technologies are competitive depends on the shape of these two cost curves. From this point of view, it is useful to distinguish between mature technologies (e.g. hydropower, geothermal, passive solar in buildings), technologies that have or are entering the market (e.g. wind, ethanol from corn, active solar in buildings) and advanced technologies for future supplies (e.g. bio-derived methane, transportation fuel from energy crops, grid-connected photo-voltaics). (For details see SOLAR ENERGY RESEARCH INSTITUTE(1990).)

In the light of these technological considerations, it appears that renewable energy sources are only likely to contribute modestly to a reduction in CO_2 emissions by the year 2005, provided energy prices develop as in the business as usual scenario and provided no decisive policy action is taken. However, the further the horizon reaches into the future, the larger the greenhouse gas emission reduction potential represented by renewable energy technologies. In particular in the case of ambitious CO_2 emission reduction targets, renewable energies have a significant role to play.

A second class of energy technologies to be considered in the context of fuel substitution consists of **nuclear energy** technologies (fission and fusion). However, independently of the acceptance issue, the question of the size of the economic potential of these technologies is subject to much dispute. Without entering into too much the detail here, the answer strongly depends on what is included in the cost calculation. This not only concerns the research and development cost and the cost of decommissioning old power plants; it also concerns the cost of a possible radioactive contamination and the welfare cost if this type of energy technology is imposed against the will of an important part of the population.

Even when abstracting from these issues, nuclear energy is unlikely to contribute significantly to a CO_2 emission reduction in the next 10-15 years. This is simply due to the time required to convince the population of the need for nuclear energy as well as to plan and build such power stations.

(b) What can be done to exploit the fuel substitution potential?

The most evident and at the same time the most important mechanism for encouraging a substitution of carbon intensive fossil fuels by fuels with low or zero carbon content is a <u>lasting change in relative prices</u>, such that prices reflect the full social cost of fossil fuel use.

In addition to changing relative prices, governments can aim at <u>removing institutional as well as technological constraints</u> to the use of renewable energy. In this context, public <u>financing of basic research and development</u> in renewable energy sources can significantly accelerate substitution in the long-run. The effectiveness of this mechanism has been demonstrated in a study undertaken in the United States (SOLAR ENERGY RESEARCH INSTITUTE(1990)). Two different scenarios were analyzed. In the first, a "technology-push" approach was adopted, accelerating public funding of research and development in order to hasten the development of cost-competitive technologies. In the second ("market-pull") scenario, it was assumed that the heightened concern about the externalities of conventional energy production leads to a price premium for clean technologies. The results of the analysis indicated that in the medium-term (30-40 years), the R&D intensification strategy would lead to a higher amount of installed renewable energy capacity than the price premium scenario. However, after this period both strategies tend to give similar results. The study also revealed that such an R&D strategy could allow the doubling of the share of renewable energy in 2020 compared to the business-as-usual scenario. It is important to emphasize, however, that in view of the long lead times such an R&D intensification has to start now in order to attain such a significant increase in the share of renewable energy by the first decades of the next century. Thus, what is needed now is a consistent long term strategy.

5.3.3. The aggregate: emission reduction cost curves

As has been shown, there is an important potential of economically advantageous measures to reduce energy related CO_2 emissions. However, in order to devise an economically optimal emission reduction policy, it is necessary to integrate the individual potentials identified above. Thus, for a rational choice of measures to exploit the different emission reduction potentials, it would be desirable to have what one might call "a social CO_2 emission reduction supply curve". Ideally, such an aggregate supply curve is the result of the (horizontal) aggregation of disaggregated, sectoral emissions reduction potentials, ordered according to their respective unit emission reduction costs.

What do such aggregate emission reduction cost or supply curves usually look like?

In view of the enormous informational requirements, it is not surprising that few such curves have been elaborated yet. In addition, due to the fact that the exploitation of one individual potential is not always independent of the measures undertaken to exploit another potential, it is not sufficient to simply aggregate the individual potentials in order to arrive at an aggregate curve. Nevertheless, the available material suggests some interesting conclusions.

Concerning world-wide aspects, McKINSEY & COMPANY(1989) has attempted to specify, in an indicative way, emission reduction cost curves for **three regions of the world.** The authors conclude that due to limited low-cost opportunities available in the developed nations of the OECD, global cooperation is needed to exploit a large, low-cost potential in developing countries.

For the **Community Member States**, the Community's JOULE programme is aiming at constructing aggregate emission reduction supply curves. The first preliminary and still incomplete (industry and services are not yet included) results of this study are presented in graph 13 for ten Member States. The message emerging from this analysis is clear: the present energy system in all Member States contains a number of inefficiencies and, therefore, does not constitute the least-cost solution to providing the required energy services. Provided these inefficiencies are removed, it is therefore possible to reduce emissions without incurring additional net costs <u>compared to the present situation</u>, even if the individual emission reduction measures represent additional costs <u>compared to the optimal least-cost energy system</u>. The results for four countries (Belgium, the Netherlands, Germany and the United Kingdom) shall be briefly summarized here (see COHERENCE(1991) for details and other Member States):

In **Belgium**, the combination of energy saving measures with additional investments to reduce CO_2 emissions would appear to allow energy related CO_2 emissions to be reduced by approximately 15% in 2010 compared to 1988 emissions. The total discounted energy system cost of such an emission reduction by approximately 24 mill. tons of CO_2 in 2010 has been evaluated at 70 billion BF (approx. 4 bill. ECU) compared to the least-cost solution. (In this context, it is interesting to note, however, that even with a 15% emission reduction the total (discounted) costs of the energy system would be lower than in t reference scenario due to the higher degree of energy efficiency in the emission reduction scenario.). Moreover, here as elsewhere, the calculation does not even yet take into account the monetized environmental benefits from reducing emissions. When considering the fact that Belgium's emissions in the "conventional wisdom" scenario are projected to increase by only 4% between 1990 and 2010 (see table 3), the overall emission reduction potential appears to be noticeably smaller than in some other Community countries (see below). It seems impossible to reach the emission reduction target without expanding nuclear energy.

With respect to the **Netherlands**, it appears that a CO_2 emission reduction of only a little over 5% between 1988 and 2010 could be achieved without any net discounted costs. The major part of this emission reduction can be attributed to changes in the power generating sector (notably a switch from coal to natural gas). An expansion of the nuclear energy capacity is not required. When taking into account the forecast increase in emissions contained in the "conventional wisdom" scenario, the results suggest the possibility of producing 2010's GDP with approximately 20% less CO_2 emissions than in the conventional wisdom scenario without any net economic energy system costs.

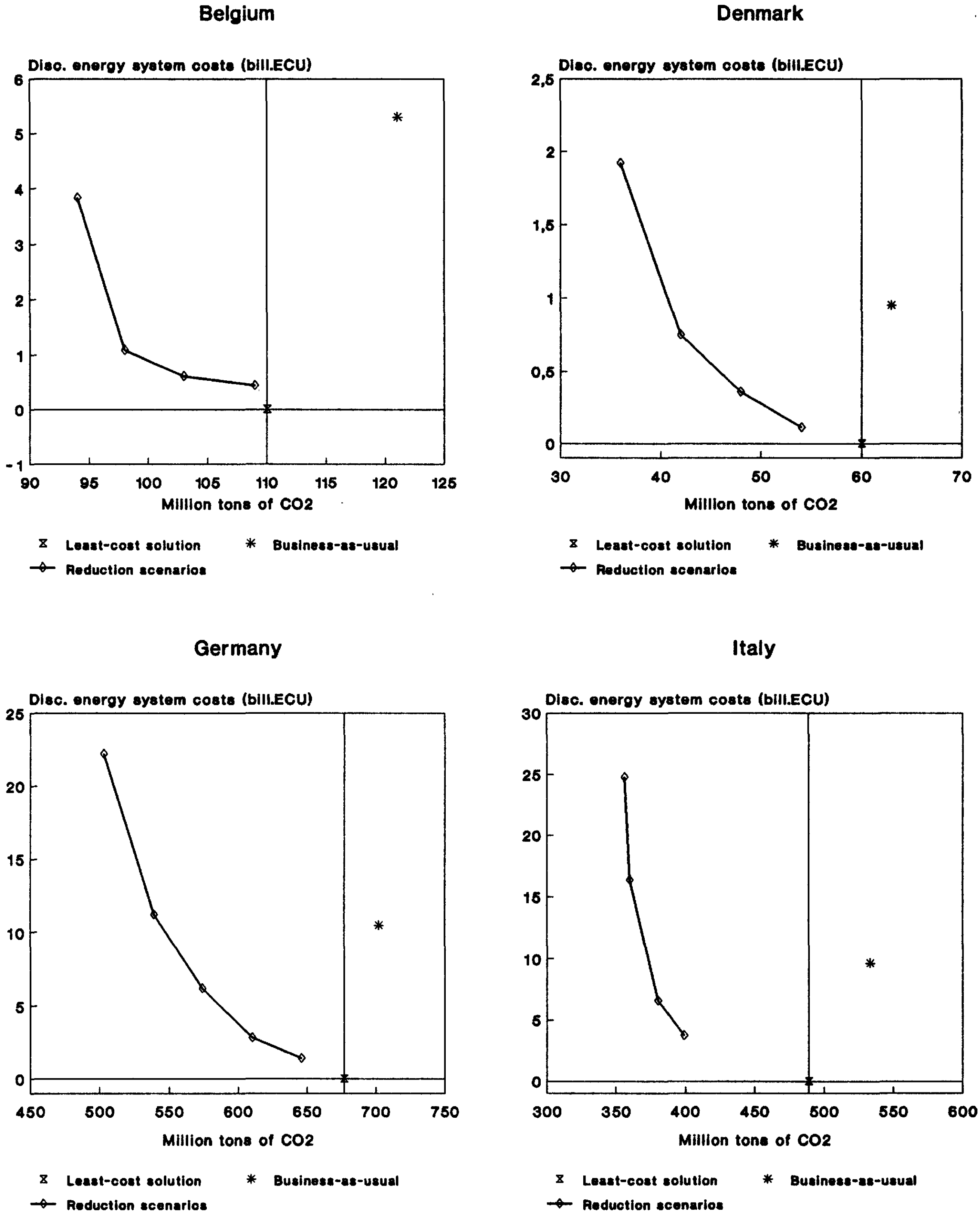
The JOULE programme results can be compared with two other studies focusing on the **Netherlands.** On the basis of a dynamic linear programming model, KRAM and OKKEN(1989) studied the scope for cost efficient CO_2 emission reduction options in the Netherlands. The authors start off with two baseline scenarios, one scenario illustrating a nuclear supply-oriented all-electric strategy, the other a demand oriented gas strategy. They then calculate the cost of reducing emissions in accordance with the Toronto target (i.e. aiming at a 20% reduction by the year 2005 and a 50% reduction by 2020). The cost (investment, operating, maintenance and salvage cost) of attaining these targets lies in the order of Dfl 36-42 per ton of avoided emissions. This represents less than 0.5% of Dutch GNP. In the study, a modest carbon charge (between Dfl 15-23 per ton of CO_2) is imposed in order to finance the CO_2 emission reduction expenditure.

A third study focusing on the situation in the Netherlands has been undertaken by McKinsey (WINSEMIUS(1990)). The main conclusion of this evaluation is that measures to ensure a stabilization of CO_2 emissions by the year 2000 would only imply relatively modest costs. If financed by an increase in energy prices, prices would have to rise by 1-3% in order to cover the additional costs. Thus, the JOULE programme results appear to lie somewhat at the pessimistic end of the range of results for the Netherlands.

For the Federal Republic of **Germany**, the JOULE programme estimates indicate that a reduction in CO_2 emissions of the order of 25% compared to 1988 by the year 2010 would be possible, even without an increased reliance on nuclear energy. The net discounted energy system costs of such a reduction are evaluated at less than DM 30 billion. The major contribution to this emission reduction takes place in the power generation sector. It is interesting to note that an emission reduction by only 20% instead of 25% is only half as costly and is, moreover, calculated to be associated with a net economic gain compared to the reference case. When looking at the sectoral breakdown of the additional expenditure required for achieving a 25% emission reduction, it can be noticed that the main financial gain would be located in the coal and oil supply sectors, a result of the reduced fuel consumption in those sectors. On the other hand, the additional expenditures needed in order to implement the energy conservation measures are mainly occurring in the tertiary and domestic sectors, where the main energy saving potential exists.

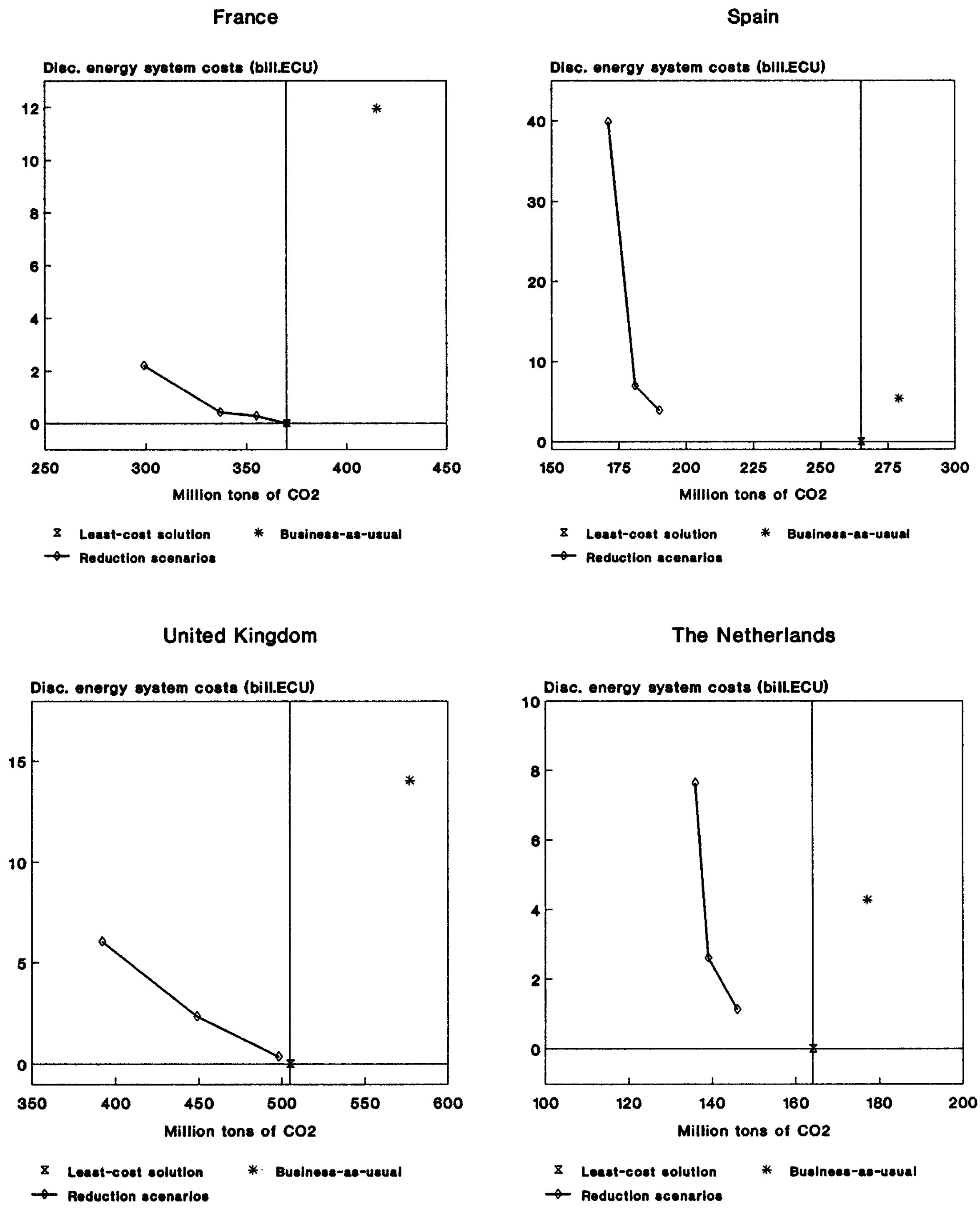
GRAPH 13: CO2 EMISSIONS AND DISCOUNTED ENERGY SYSTEM COSTS

(Emissions in 2010; costs comp. to the least-cost solution)

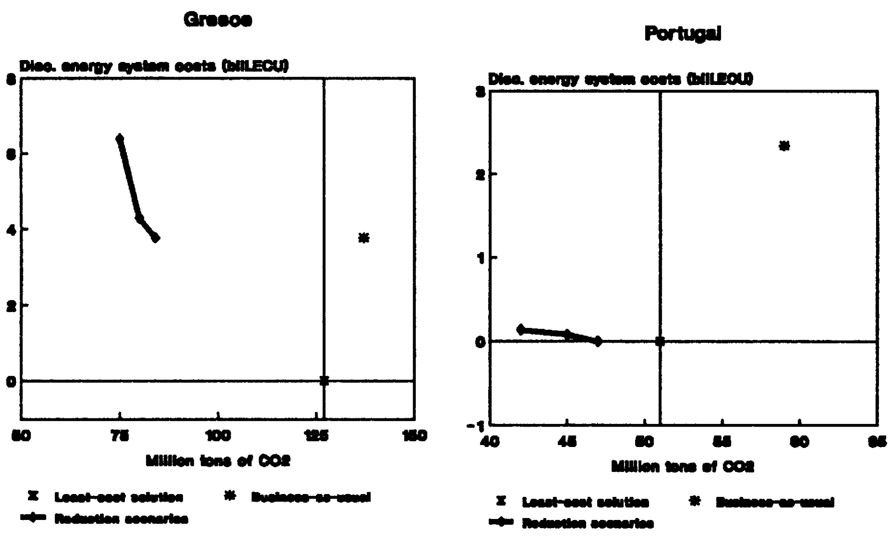


Source: COHERENCE(1991)

GRAPH 13: (continued)



GRAPH 13: (continued)



Although for Germany no alternative set of emission reduction cost curves has been established, the results of the studies undertaken for the Parliamentary Commission allow comparison with at least one point on such a curve. This point estimate concerns the economic cost of a reduction in CO_2 emissions by about 30% between 1987 and 2005. These costs consist of the necessary investment and operation costs and are evaluated to be of the order DM 5 billion per year, less than DM 100 per capita in 2005 (for details see DEUTSCHER BUNDESTAG(1990b)). Even if one were, on an ad hoc basis, to add to this figure the same amount reflecting transaction costs, according to this study, the total net cost of the emission reduction would only be around DM 12 billion per year, approximately DM 55 per ton of avoided CO_2 emission. This appears to be significantly lower than the costs arrived at on the basis of the above-mentioned JOULE programme results, which arrive at an average cost of approximately twice this figure per ton of CO_2. (Again, these figures do not take into account the economic benefits from mitigating global warming.) As expected, the elimination of barriers to the efficient use of energy, evaluated on its own, can be expected to lead to a considerable net economic gain (DM 27 per ton of avoided CO_2 emission).

Concerning the **United Kingdom**, the preliminary JOULE results suggest that a reduction of CO_2 emissions in the order of 30% between 1988 and 2010 is not only feasible, but would even be associated with a net economic gain (see graph 13). This finding can mainly be explained by the presently high share of coal (comparable to the situation in Germany). Compared to most other Community countries, the share of renewable energy sources is relatively high in the UK emission reduction scenario.

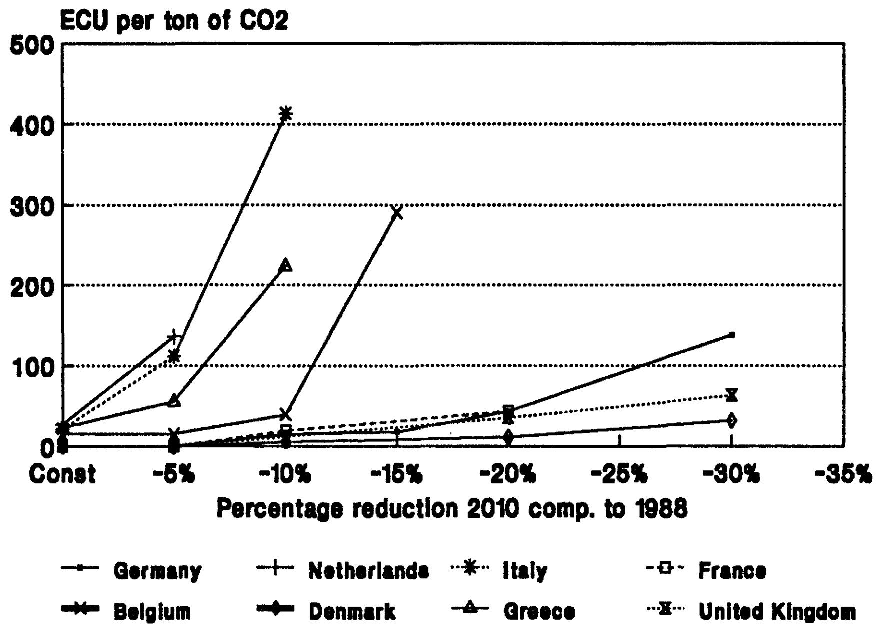
Two other studies have tried to construct such aggregate cost curves for the **United Kingdom**. JACKSON and ROBERTS(1989) have surveyed the costs of measures to cut CO_2 emissions. Their main conclusion is that it would be possible to achieve the Toronto conference target of reducing emissions by 20% by the year 2005. In the authors' view, the target can be comfortably achieved using energy efficiency, combined heat and power (CHP), fuel switching and renewables, without even taking into account the reductions possible in the transport sector. The average reduction costs would in fact be negative (i.e. there would be a net gain), although the marginal cost of reducing emissions by more than 200 million tons of CO_2 would clearly be positive.

The second study (LEACH and NOWAK(1989)) attempting to evaluate the emission reduction potential in the **United Kingdom** analyzed a scenario aiming at a 23% reduction compared to 1987. The results showed that just over half of the emission reduction would come from changes in energy demand, mostly due to improved energy efficiency, but also some from fuel switching. Transport came out as the most difficult sector for effecting emission reductions, given the expected large rise in traffic assumed in the baseline.

Why do aggregate emission reduction cost curves differ between different studies and what conclusions can be drawn from these analyses? Aggregate emission reduction cost curves not only differ between countries (reflecting the different circumstances), but also between different studies concerning one specific country.

Concerning the differences between countries, graph 14 compares the marginal CO_2 emission reduction costs for eight Member States of the European Community. These differences reflect at the same time country-specific factors (like the present fuel-mix and the availability of alternative energy sources) and differences in baseline emission growth. As such, these data clearly demonstrate the economic costs of adopting a "Toronto-type" emission reduction scheme (without allowing for emissions trading).

GRAPH 14: MARGINAL UNITARY EMISSION REDUCTION COSTS



Source: COHERENCE(1991)

As to the differences in the results <u>for one individual country</u>, four main reasons can be given for such differences:

(i) <u>Modernity of technologies assumed</u>: due to rapid technical progress, using data that are already a few years old can significantly overstate the cost of energy saving measures.

(ii) <u>Accounting differences</u>: this does, among other things, concern the question of the base year (which might have particular characteristics) and the choice of the discount rate.

(iii) <u>Methodological differences</u>: for example, whether reduced maintenance costs are taken into account, whether multiple benefits are captured or what is assumed with respect to the speed of diffusion / penetration rates.

(iv) <u>Level of detail</u>, both in terms of the number of options considered and in terms of the size of savings counted.

As to the conclusions to be drawn from the above analysis, there seems to be a general consensus, first, that our present energy systems do not represent the least-cost solution to providing the present demand for energy services (due to existing inefficiencies) and, second, that in some countries the costs of emission reduction rise steeply from a certain reduction level onwards.

5.4. "Bottom-up" versus "top-down": some tentative conclusions

When comparing the results obtained on the basis of the "top-down" approach with the results gained by adopting the "bottom-up" approach, the impression is that the latter approach is clearly more "optimistic" as far as the economic potential for emission reductions is concerned. How could this be explained since, ideally, "micro-" and "macroeconomic" analysis should arrive at similar conclusions? A priori, two - mutually compatible - reasons could be offered as an explanation:

- First, although there undoubtedly exists a potential for economically efficient emission reduction associated with energy efficiency improvements, top-down studies usually "define away" this potential by assuming perfect markets. However, in real life, this "efficiency gap" (see GRUBB(1990) and GRUBB et al.(1991)) is of great importance for devising least-cost or "no regrets" policies. What has to be kept in mind here is that, due to the existence of market imperfections, part of the existing emission reduction potential cannot be exploited by relying on traditional forms of taxation. Thus, it is not surprising that reliance on only one particular instrument is insufficient to exploit the full potential. By definition, the market mechanism can only play its role where a market exists and functions properly: Hence the need for an appropriate instrument-mix of taxes and other policy instruments.

- Second, the "bottom-up" approach could overstate the emission reduction potential that can already be profitably exploited from the point of view of private economic agents by neglecting "hidden costs". This is of particular importance with respect to the household sector, where search and information costs may be high. Alternatively, private economic agents might not be the rational subjects supposed by economic theory. To that extent, the "real" potential would be smaller that appears at first sight. It has to be stressed, though, than it would nevertheless be profitable from society's point of view to use this potential.

What can be concluded from the above discussion? The main conclusion must be that the cheapest way of rapidly reducing emissions consists undoubtedly of promoting the rational use of energy. As is illustrated by the preliminary JOULE programme results (see graph 15), the profitability or costliness of CO_2 emission reduction policies depends crucially on the exploitation of the available scope for energy efficiency improvements. There is a considerable amount of information suggesting that an important emission reduction potential exists, the exploitation of which would offer clear economic benefits to society, even when abstracting from the environmental benefits. It is the exploitation of this potential that leads to the "negative cost" part of the emission reduction cost curve which is so abhorrent to an academic economist's mind. Although the evidence is only sketchy, this potential might tentatively be estimated to be of the order of at least 15% of the Community's forecast CO_2 emissions in 2010. The only question is, how much of this potential can be exploited by implementing appropriate policy measures? If one adds to this figure the potential for substituting fossil fuels with high carbon content (e.g. coal) by fossil fuels with low carbon content (e.g. natural gas) or non-fossil fuels (e.g. renewable energy sources), preliminary work suggests that cost-effective emission reduction policies should in principle allow emissions in 2010 to be some 20-25% lower than in the conventional wisdom scenario (i.e. 10-15% lower than in 1987), without excessively burdening the economy.[26]

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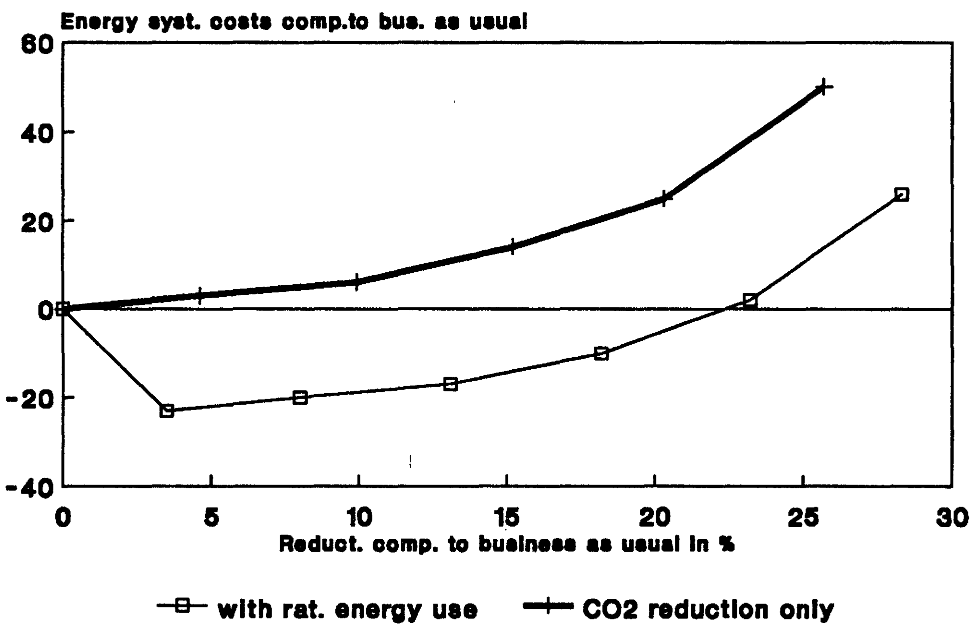
[26] Michael GRUBB (1991) and his co-authors arrive in their analysis at the conclusion that, on the basis of known technologies, reductions in CO_2 emissions of the order of roughly 1% per annum might be

However, a few cautionary remarks are necessary. First, as has been noted above, the potential differs significantly between countries, implying the need for a differentiated and flexible objective setting. Second, a small difference in the amount of emission reduction can imply a much larger change in costs. Third, this is only the socially profitable potential. To fully exploit this potential, significant policy changes along the lines discussed in this paper are required. Only the implementation of efficient and comprehensive policies will allow the gap to close (or at least narrow) between this economic potential and the achievable emission reduction potential. Aiming at a high reduction target without undertaking these policy changes could indeed be costly.

GRAPH 15: THE COSTS OF EMISSION REDUCTION WITH AND WITHOUT RATIONAL ENERGY USE
(Illustrative example)



Source: Own calculations based on COHERENCE data for Germany

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obtained in many developed economies at little if any net economic cost, if appropriate policies were adopted.

6. DEFORESTATION AND AFFORESTATION

6.1. The importance of forests in the context of the Greenhouse problem

Forests play an important role in the context of global warming. Next to oceans, they represent the second largest storage of carbon. Moreover, forests play an active role in the atmospheric CO_2 cycle. It is therefore necessary to address this issue briefly. Usually, in an undisturbed, mature forest, the absorption of CO_2 equals the release of CO_2. Thus, in the long-run, such a mature forest is - contrary to the oceans - not a net CO_2 "sink". However, changes in land use accompanied by deforestation or afforestation can alter the net CO_2 balance with the atmosphere.

As to the contribution of deforestation to net CO_2 emissions, it is difficult to obtain reliable data. Estimations indicate that deforestation could contribute between 7-30% of worldwide carbon dioxide emissions. (For comparison, the Community's share in total CO_2 emissions is close to 13%.) Net deforestation is particularly important in tropical areas of South America, Asia and Africa (see table 14). The last internationally comparable figures for tropical deforestation relate to the year 1980, when some 11.1 million hectares (an area greater than the size of Portugal) were lost (COMMISSION(1990c)). For some tropical countries, the share of CO_2 emissions stemming from deforestation even exceeds by several times the CO_2 emissions related to fossil fuel combustion. (Brazil, for example, is considered to emit six times as much CO_2 through deforestation as through fossil fuel combustion. (See, e.g. FLAVIN(1989)).

TABLE 14

DEFORESTATION AND REFORESTATION IN THE WORLD IN THE 1980s

Region	Average annual deforestation 1980s		Average annual reforestation 1980s
	Extent (in 1000 ha)	Percent of existing forests	Extent (in 1000 ha)
Africa	3.822	0.6	355
North and Central America	1.251	0.1	2.552
South America	11.180	1.3	760
Asia	4.405	0.9	5.708
Oceania	26	0.0	117

Source: *WORLD RESOURCES INSTITUTE (1990)*

6.2. Measures to halt deforestation

As the causes of deforestation in tropical countries are numerous, approaches to halt this process cover a wide range of measures. These range from birth control via land reform, better forest management, more efficient fuel use and fuel substitution to measures which help poor countries to improve their financial situation. In the following paragraphs, the feasibility and economic efficiency of three frequently proposed measures to promote the end of deforestation, Debt for Nature Swaps, direct transfer payments to rain forest countries and trade restrictions for tropical timber will be briefly assessed.

6.2.1. Debt-for-nature swaps

The debt-for-environment or debt-for-nature swap (DNS) offers to highly indebted countries the possibility of exchanging part of their debt against the preservation of forests. Although debt-for-nature swaps have not been conceived as a way to address the greenhouse issue, they could nevertheless have a useful role to play in this context. The underlying idea is that in reducing their debt burden, forest countries are not obliged to export wood to pay off their debt. In practice, a Non-Governmental Organisation (NGO) buys part of the debt from a creditor bank and transfers it to the debtor country in exchange for the obligation to take action in protecting the forests.

From a theoretical point of view, debt-for-nature swaps contain a fundamental contradiction. If the debt were the main cause for the deforestation in a country, a direct remission of debt or a moratorium would be a more direct and efficient way to achieve the goal. However, the causal relationship between debt and deforestation seems far from being that clear-cut. Hence DNS can be considered as a debt reduction scheme with environmental conditionality where the causal chain debt/deforestation is only of secondary importance.

Furthermore, debt-for-nature swaps do not (or at least not directly) address the developing countries' main preoccupation, namely the lack of new credits ("fresh money"). Only to the extent that the reduced debt burden improves a country's credit rating or otherwise frees resources for development and investment DNS correspond to development needs. In the absence of such an effect, debt-for-nature swaps are only likely to be acceptable for tropical forest countries if direct transfer payments compensate at least partly for the opportunity costs of forest conservation (lost revenue from timber exports and of agricultural products grown on cleared forestland).

In addition, countries with tropical forests but only a small debt burden like Malaysia, Burma and Indonesia would have no economic incentive to participate in the DNS scheme. On the contrary, if DNS could be executed on a consistently large scale with high debt countries, less indebted countries would tend to increase their timber exports as world market prices would rise due to a reduction of supply from highly indebted countries.

Practical experience with DNS has not proved to be very favourable either. Until now, the volume of DNS operations has been insufficient to ensure a significant reduction of LDCs' debt. Furthermore, the acquisition of debt on secondary finance markets tends to raise the price of these bonds which makes this way of debt reduction more expensive and less feasible. However, from a conceptual point of view, the idea of debt-for-nature swaps by no means has to be limited to private debt being bought by NGOs on secondary markets.

Governments could also negotiate such swaps involving public debt, thereby considerably raising the potential amount of resources involved.[27]

6.2.2. Direct transfer payments to tropical forest countries

Direct transfer payments to tropical forest countries would be tied to the obligation to undertake action in preserving forests. Although such payments would appear to be not in line with the polluter pays principle when only seen from the CO_2 emission point of view, such a scheme which compensates for global external effects of deforestation would be economically desirable if it increases global welfare. This is particularly the case if the benefits from avoiding a loss in biodiversity accrued to all countries (i.e. also to industrial countries).

Theoretically, the optimal amount of a transfer payment is determined by the shape of two cost-curves, the marginal opportunity cost of forest preservation (lost revenue from timber exports and other agricultural products grown on cleared forest land as well as cost of substitution of firewood by other energy sources) and the marginal cost of environmental damage caused by deforestation. The underlying idea of such transfer payments is to give tropical forest countries an incentive to reduce forest clearing to a level where its lost revenues from forest clearing equal the global social costs of deforestation and not only national social costs. The size of the transfer is bounded by the benefits for the paying country on the one hand, and the loss of economic value to the recipient country, on the other.

Practically, the quantitative determination of the cost curves, especially the marginal cost curve of environmental damage caused by deforestation, is far from being evident. The estimation of environmental damage like global climate change is particularly difficult because deforestation is only one of several causes of global warming. Furthermore, as has been discussed in chapter 4, the quantitative evaluation of costs and benefits is complicated by the difficulty of valuing the social costs of species losses.

As to the institutional organisation of the transfer scheme, two different approaches can be distinguished, a bilateral and an international one (e.g. an environmental fund or facility). A system of bilateral transfer payments has the disadvantage that it would increase economic dependencies between tropical forest countries and certain industrialized countries. An international solution via a global environmental fund could, on the other hand, guarantee an equal and just transfer mechanism. The conception of the scheme must, however, allow for an earmarking of the funds in order to ensure that the money is really used for forest conservation measures. By listing tropical forestry as one of the five key areas for environmental aid in LOME IV, the Community and ACP countries have already demonstrated their willingness to use new resources in this sector.

The financial resources for an international environmental fund should come from industrialised countries according to the part each country contributes to the global costs of environmental damage. The evaluation of the regional distribution of such costs could be difficult. In such a case a distribution according to the GNP of each country could be envisaged. Concerning the amount of resources required, it is argued that even on the basis

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27 A similar idea is currently being explored in the context of a proposal by the Polish government concerning a debt-for-environment swap. The proposal is to set up an environment fund to be financed by a swap agreement between Poland and (some of) its Paris club creditors. According to the proposal, part of the Polish debt service payments would be allocated to the environment fund, which would exclusively focus on measures to reduce Poland's contribution to global environmental problems, including the greenhouse effect.

of conservative estimates, the need for forestry aid by development agencies may exceed $ 1.2 billion a year, about twice the 1988 level (see e.g. COMMISSION(1990c)). This would be significantly more than the $ 4 billion over a five year period suggested in the original outline for the Tropical Forestry Action Plan (TFAP, see COMMISSION(1989a)).

6.2.3. Trade restrictions for tropical timber

Trade restrictions for tropical timber are sometimes considered as an alternative instrument to curb deforestation. The aim of such measures is the reduction of tropical timber consumption through a limitation of the world timber trade. These measures can take several forms:

- import stops or prohibitive import quotas

- customs duties or indirect taxes

- moral persuasion of importers and consumers to reduce timber consumption.

These instruments can only be successful if the export share of economically used tropical timber is sufficiently high. First, it must be said that timber cutting is only one cause of tropical deforestation; fire clearing in order to obtain agricultural land seems to be at least an equally important one. Moreover, only 14% of cut wood in tropical forest countries is used as timber (DEUTSCHER BUNDESTAG(1990a)). Of this timber, one third is being exported, so exports cover only around 4% of the wood cut. These figures demonstrate that simply for quantitative reasons trade restrictions for timber would only have a limited effect on tropical forest countries and can therefore not be considered as an option for slowing down global climate change.

Further conditions for successful timber-import restrictions must be met. First, the elasticity of demand in importing countries must be sufficiently high in order to guarantee a substantial reduction of timber imports when prices rise in response to a supply reduction. This will not be true in the case of tropical timber used for luxury furniture. The price elasticity of demand is low in this case due to the snob effect. Second, it must be ensured that all importing countries apply the restrictions, as otherwise trade will be diverted to countries which do not adhere to import restrictions.

Finally, apart from the low effectiveness of protectionist measures, timber trade restrictions lack legitimacy from the point of view of distributional justice. A worldwide import stop for timber would deprive tropical developing countries of their right to exploit a natural resource, even if such an exploitation were undertaken in a sustainable way. This is especially hard for countries where timber is the most important resource for financing economic development.

As a <u>conclusion</u>, it can be said that the three considered measures to halt deforestation show conceptual and practical drawbacks. This is particularly true for debt-for-nature swaps and timber trade restrictions. Direct transfer payments to tropical forest countries could, however, prove to be efficient under certain conditions even though at times they may not be in line with the Polluter Pays Principle. In any event, it is important to ensure that the transfer payments are conditional on domestic policy adjustments required to eliminate or at least reduce the underlying economic, social or institutional causes of deforestation.

6.3. Afforestation

One way of increasing the net CO_2 uptake of the biosphere is by enlarging the stock of biomass through afforestation. Estimations of the land area required to plant the forests needed to sequester 2.9 billion tonnes of carbon annually vary between 300 million ha (a landmass the size of Zaire) and 600 million hectare. The size of the area required depends on the species of trees considered for afforestation. As a matter of fact, the carbon uptake of different species diverges considerably (between 8 t C/ha and 37 t C/ha according to ERL(1990)). The corresponding economic costs of afforestation measures consist mainly of the establishment costs for forest plantations and the cost of land procurement. Estimations for these costs vary considerably from one source to another.

Most studies come to the conclusion, however, that such measures are generally much more likely to be economically advantageous for tropical rain forests than for forests in temperate zones. McKINSEY & COMPANY(1989), for example, estimate the costs of forest management, afforestation and reduction of deforestation to range from $5 per ton of carbon conserved ($43 per hectare per year) in the tropics to $28 (140ha/year) in OECD countries other than the USA. NORDHAUS(1990a) concludes that the total costs of carbon sequestration lie between $41 per tonne of carbon in the tropical countries and $114 in the United States. This picture is also broadly confirmed by a study undertaken by ERL(1990) assessing the cost effectiveness of selected options to reduce CO_2 emissions in developing countries.

SEDJO(1989), on the other hand, presents comparatively more optimistic estimates of the cost effectiveness of afforestation programmes. He evaluates the total costs to be of the order of $ 400 per hectare in tropical zones and $800 per ha in temperate zones. Over an average maturation period of forests of around 40 years, these costs would be equivalent to $10 ha/year ($2 per tonne of carbon sequestered) in the tropics and $20 ($4 t of carbon) in temperate regions.

Concerning the differences between different cost effectiveness studies covering the same region, these differences are largely due to three main factors:

- <u>the assumed opportunity cost</u>. If, for example, it is assumed that the alternative to using the land for forests is of highly productive agriculture, reforestation is rarely economical. On the other hand, when assuming unproductive use, forests can also be a viable alternative from the economic point of view.

- <u>the assumed economic benefits from forests</u>. While some studies only include wood in the cost effectiveness study of forestry projects, others find that receipts from non-wood forest products in the tropics (fruit, medicinal plants, etc.) can even be ten times as high as the receipts from sustainable wood harvest (see e.g. ERL(1990)). Moreover, this latter calculation still neglects the environmental benefits from halting deforestation (reduced soil erosion, protected biodiversity, reduced global warming).

- <u>the assumed cost of land procurement for afforestation measures</u>. The estimated costs of land procurement in temperate zones, for example, vary in different studies from $100 to $400 per ha. The prospects of finding a sufficient area of land suitable for afforestation appear to be good. According to different sources, the area potentially available is estimated to lie between 100 and 400 million ha (see HOUGHTON(1988) and McKINSEY(1989)). Although this area might not be sufficient to completely meet the land requirements (300 to 600 ha) to sequester the entire annual increase in CO_2 emissions, it would still allow the execution of an ambitious afforestation programme.

A final question has to be discussed in the context of an afforestation strategy: What to do with the timber produced? As long as afforestation is only seen as an option "to buy time" by slowing down the increase in atmospheric concentrations of carbon dioxide until other options become available (so-called peak-shaving), the problem will not arise in the next 30-50 years. If, however, afforestation were to be seen as part of a long term strategy against global warming, ways have to be found to use the wood of mature forests without releasing CO_2 (e.g. without burning the wood).

It can be concluded from this discussion that afforestation and sustainable forest management programmes seem to have certain advantages in terms of cost effectiveness in comparison to other greenhouse gas emission reduction options. At the least, such programmes should be part of a comprehensive package of measures to address the greenhouse problem. Moreover, action in this area will bring about other environmental benefits on a local or regional scale (such as, for example, maintained biodiversity).

7. THE INTERNATIONAL DIMENSION

7.1. Defining common and/or individual targets

7.1.1. Reaching an agreement on a common policy

As already set out in chapter 3, the greenhouse problem is a clear case of a problem requiring global action. No individual country or even country group is in a position to halt global warming by taking measures in an isolated way. The question therefore arises of whether and how a global agreement can be reached that is necessary to assure an effective policy.

A priori, economic theory suggests that it will be difficult (though not impossible!) to reach such an agreement. The reason for this lies in the fact that emission reduction is an extreme case of what economists call a public good: while an individual country undertaking emission reduction investments (beyond the amount which is justified on purely national economic grounds) has to carry the full cost of this measure, the benefits from such an action will not only be small for this country, but will also accrue to all other countries. Each country has thus an economic incentive to avoid such investments and to benefit from the reduction investments undertaken by other countries (e.g. a subgroup of countries that have reached an agreement). If, however, too many countries attempt to act as free riders, it is unlikely that any country would be willing to undertake such measures or to sign a respective agreement.

In the context of the greenhouse issue, this dilemma is furthermore aggravated by the fact that some might think that they would even gain from global warming. It is therefore useful to look briefly at what can be learned from game and negotiation theory as well as from the experience with other environmental agreements in the past. Both types of analysis show the importance of having the right (economic) incentives for reaching an (optimal) agreement (see e.g. BARRETT(1989) and BARRETT(1991c)). Moreover, there is the risk that international agreements are designed in such a way as to give countries an (implicit) economic incentive to look for ways to avoid emission reduction measures.[28] However, the evidence presented in this study has illustrated that there are likely to be important possible gains from an international solution. If, for example, the cost of reducing energy related CO_2 emissions in industrialized countries were of the order of \$20-50 per ton of carbon, while the cost of avoiding emissions from deforestation in developing countries was only approximately \$6, then it becomes clear that the economic gains from an international solution could be enormous and the question of how these potential gains can be distributed to create incentives to participate becomes predominant. It is important in this context to distinguish the efficiency aspects of an economically sound international solution from this equity aspect of the distribution of gains and costs.

The above discussion has clearly demonstrated that the issue of how developing countries could receive the (economic) incentives to participate is of central importance. This is not only due to the CO_2 sequestering potential of tropical forests and to the CO_2 emissions due to deforestation, but also to the drastic rise in energy related greenhouse gas emissions forecast for the next century (see the example of China!). This forecast sharp rise is mainly the consequence of continued strong population growth, high and at present largely

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[28] To give an example, if an agreement were to state that all low-cost emission reduction measures should be undertaken, countries might be tempted to invest more effort in trying to prove that they have only high-cost options available than in trying to identify low-cost options. A similar problem could arise in cases where an aggregate emission reduction target has to be allocated among countries, giving countries the incentive to plead for low reduction targets in their specific case (see GRUBB(1989) on this issue).

unsatisfied economic welfare aspirations and a coal dominated fossil fuel base. It has to be recognized in this context that, in view of the pressing short-run economic problems many developing countries face today, expensive emission reduction measures can hardly be expected from these countries. This is particularly true as the benefits from such measures would only accrue to future generations, generations that in all likelihood will be better off economically than present generations.

One should not forget, however, that present energy use in these countries is much less efficient than in industrialized countries: electrical transmission and distribution losses are twice as high as for OECD countries, energy efficiency in industrial processes is sometimes only half the rate common in developed countries (see e.g. LAWRENCE BERKELEY LABORATORY(1989)). It is estimated (ASSESSMENT(1990)) that, on average and only covering visible and attainable opportunities, 20-25% of energy use in LDCs could be saved by taking measures with a payback period of two years or less. Thus, even when allowing for higher economic growth aspirations, the emission reduction potential in less developed countries is significant. The exploitation of this potential would be in the interest of developing countries as well as in the interest of the international community as a whole.

For these reasons, the issue of <u>financial transfers</u> as well as of <u>technology transfer</u> is of crucial importance. Without such transfers, it is unlikely to prove possible to reach a broad international agreement allowing the exploitation of the available potential of low cost emission reduction.[29] This transfer of resources could be organized on a bilateral basis, within a Global Environmental Facility (jointly managed by UNEP, UNDP and Worldbank) or within a new Global Climate Fund.

7.1.2. Deriving targets for individual countries

Assuming that despite the above described problems a group of countries (e.g. the Community Member States or even all UN Member States) agree on the need for a common emission reduction policy, either by agreeing on a global quantitative emission reduction target (e.g. of the Toronto type) or by reference to a common cost threshold for emission reducing investments (represented, for example, by a corresponding tax rate), the next question is what the global agreement implies operationally for the individual participating countries. Basically, it is useful to distinguish between the following possible schemes (for a comprehensive analysis of these issues see also GRUBB(1989)):

(a) Tax based schemes

- <u>A uniform carbon tax at the national level</u>: Theoretically, all countries could agree to levy the same tax or charge on fossil fuels (or on CO_2 emissions in general). If the tax rates were identical and the revenues remained at the national level, no international resource transfer or distorted competition issues would arise. Moreover, if pre-tax energy prices were similar internationally (i.e. a single market for energy) and provided the scheme ensured that countries were unable to compensate the tax effects by paying subsidies, an economically efficient international emission reduction could be achieved. (However, there are a number of practical difficulties, not least the question of how tax rates could be defined and monitored in the presence of exchange rate fluctuations etc.)

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[29] In principle, all the ideas evoked in section 5.1.3.(b) on measures to create markets for exploiting the energy efficiency / emission reduction potential could also be transposed to the international issue. One could, for example, envisage a scheme of "international third party financing". S·· HOURCADE/SHUNKER(1990) for details.)

- A new emission tax at the international level: In principle, two ways of organizing such a tax could be envisaged. The **first option** would be that **countries** pay a tax on their (aggregate) net CO_2 emissions (for details see e.g. HOEL(1990)). The tax rate would be agreed internationally and the tax revenues could be redistributed to the countries according to some allocation rule. Each country would be free to choose its preferred way to attain the nationally optimal emission level (e.g. by regulation, tradable permits etc.). The **second option** would consist of an agreement to tax emissions internationally at **the microeconomic level**, for example in form of an international tax on fossil fuels. In both cases, a new international institution would be required to administer (and to enforce) the tax scheme. However, while countries (or governments) would be subject to the tax in the first case, private economic agents would be subject to the international tax in the second case.

WHALLEY and WIGLE(1990 and 1991) have investigated this aspect by simulating different policy instruments with the help of a computable general equilibrium model. Their analysis illustrates the importance of the rule for distributing the revenues from an international tax. In the two extreme cases that are studied (national collection and distribution of taxes versus collection and distribution by an international agency), the low income region incurs a welfare loss of about 5% of GDP in the first case (national consumption tax), while it receives a welfare gain as high as 3% in the case of an international revenue distribution proportional to population. In addition, if the tax is collected and redistributed nationally, for some regions of the world (e.g. oil producers) it is of significance whether an international tax (but with national revenue collection) is levied on energy production (advantageous for oil producing countries due to positive terms of trade effects) or as a consumption tax (advantageous for oil consuming countries). In general terms, the amount of revenues generated by an international tax might in fact be an obstacle for reaching an agreement on such a scheme (WHALLEY/WIGLE, for example, estimate the revenues generated in a 50% emission reduction scenario to be of the order of $600 billion, several percent of world GDP).

(b) Quantity based schemes

Basically three alternative approaches could be envisaged:

- Fixed **national** emission quotas: all the countries participating in the common emission reduction scheme would have to agree on a framework for deriving individual country targets from the overall emission reduction target. In its simplest form, such quotas are set by reference to a base year (e.g. "Toronto-type" targets). Alternatively, such a framework would probably be an algorithm based on a number of economic and other indicators (e.g. technological options). From the economic point of view, it is essential that this set of indicators not only includes variables like population, GDP etc., but also indicators concerning the costs of emission reduction measures. Unless the indicator set reflects the differences in the relative cost of reducing emissions between different countries, fixed national emission quotas will be economically inefficient. This also implies that uniform reduction targets for all countries are likely to be the economically most inefficient solution (see graph 15). Although they give the impression of being "just", they in fact place a higher burden on those countries that have already made significant efforts to reduce emissions or that, due to objective circumstances, have only costly options of doing so.

- Fixed **per-capita** emission ceilings: from an equity point of view, it may appear preferable to allow an equal amount of emissions per adult. Less developed countries could thereby more easily be convinced to participate in an international emission reduction scheme. Industrialized countries, on the other hand, would have to cut their emissions drastically. Several objections can be raised against such a scheme. First, as long as there are no controls on population growth, the per-capita (net) emission ceilings would have to be adjusted regularly if a fixed target in terms of atmospheric concentrations of greenhouse gases were aimed at. Second, there is no reason to believe that the energy conservation potential is smaller in the LDCs than in the industrialized countries. Third, as has been illustrated by WHALLEY and WIGLE, such a policy could lead to a severe distortion of trade patterns, with the production of energy intensive products shifting from the high income to the low income countries. Thus, per-capita emission ceilings are not a cost-effective solution to the challenge of global climate change.

- Tradable emission permits: in this case, all participating countries would be allocated a certain quantity of CO_2 emission permits. Although the allocation mechanism has to be agreed beforehand, no country would be physically restricted in its emissions. Instead, each country can decide for itself whether it is cheaper to reduce emissions or to buy emission permits from other countries. Total world emissions would be unaffected by this individual choice.

  Such a tradable emission permit scheme has several advantages. First, permits are a particularly efficient instrument in cases where it is important to respect an overall emission target and where the number of participants is not so large as to imply high transaction costs. Taxes, on the other hand, would probably have to be adjusted in a trial-and-error process to exactly attain the target. (If the target has not been attained, the question will then arise of whether this is due to an inability to find the right tax rate or due to unwillingness to undertake the required measures.) Second, tradable permits are an almost ideal instrument for a decentralized policy approach based on the subsidiarity principle as they give each participant the freedom to decide on the precise measures to be taken in order to respect the allocated emission rights. Third, tradable permits can be implemented "on top" of other agreements. If, for example, countries could agree on individual, country-specific and quantitative emission reduction targets, these could be subject to trading at a later stage (thus, in fact, they would constitute the initial allocation of emission permits). No country would be worse off with such a scheme, while some might gain significantly. Initially, such trading could even be more or less informal via a type of "clearing house". Thus, immediate full trading is not required, but bilateral trade is possible (see e.g. ECON(1991) on this issue). Regional trading schemes could then easily be established (see e.g. HANSEN/ROLAND(1990)).

  On the other hand, it has to be noted that to date there has been very little practical experience of tradable permit schemes in the Community. This might render a large-scale implementation in the near future unlikely. In addition, there are difficult issues of permit allocation and monitoring to be addressed.

One can conclude from this discussion that quantity based schemes have both advantages and disadvantages over tax/cost based schemes. If it is important to ensure that a specific quantitative target is reached, taxes are unlikely to be the best instrument and a emission permit scheme appears preferable. Moreover, the economic policy experiences of the past few decades have clearly shown the difficulty of reaching precise quantitative national targets with the help of traditional policy instruments (the so-called "fine-tuning" debate with respect to the traditional targets of full employment and price level stability).

On the other hand, national emission rights or emission quotas would probably accentuate the difficulties of dealing with the international exchange of goods and services (e.g. the energy content of exports, the issue of international air and sea transport, electricity exports/imports etc.). Although these issues would implicitly also arise in the case of taxes, quotas are likely to complicate the adjustment process. With respect to both tax and quantity based schemes, an important issue relating to the implementation concerns the amount of resources transferred internationally. Further attention therefore has to be given to this aspect when designing an international scheme by looking for ways of limiting the amount of international financial transfers while nevertheless exploiting the efficiency gains associated with such international emission reduction schemes.

7.2. Instruments, subsidiarity and the issue of international compatibility of instruments

As stressed above, the CO_2 issue (and indeed the greenhouse issue in general) calls for an agreement that, ideally, encompasses all emitters of these gases. However, this does not imply that all participating countries have necessarily to use the same policy instruments. As in other policy areas, individual countries should only be restricted in their free choice of policy instruments if a common instrument leads to superior results in attaining the target (subsidiarity principle). The question is then, whether - and if yes where - this is the case with respect to policies to reduce CO_2 emissions.

Although the discussion here cannot be exhaustive, it is necessary to briefly analyse the subsidiarity question concerning the choice of CO_2-policy instruments in the context of the single market, both with respect to taxes and standards. A priori, the problem appears to be less acute in the case of instruments directed at (production) processes or non-tradable goods and services. As all policy instruments are bound to be associated with some form of costs (e.g. either the tax payment or the compliance cost of regulations), there appears to be no important trade distorting effect. However, in dynamic terms, different policy instruments could have different repercussions on the direction of research & development and therefore of technical progress in different countries. Such an impact could, in turn, reduce the potential economic gains of having one large European market.

Concerning tradable goods, on the other hand, there could well be a conflict between the free movement of goods and the efficiency of a national environmental policy. This can be easily illustrated by reference to the example of vehicles: if one European Member State relied on a carbon tax while another Member State chose engine efficiency standards, this would either require restrictions on the trade with cars (because otherwise the cheaper cars not meeting the standards would gain a competitive advantage in the country with standards) or the national instruments would be environmentally ineffective and thus also economically inefficient.

In the same vein, it is highly doubtful whether it is economically efficient and, indeed, even operationally feasible to have one Community Member State adopting a tradable emission permit scheme, while others rely on energy taxes. Thus there would appear to be clear economic advantages to be had from adopting a Community-wide approach.

8. EXECUTIVE SUMMARY AND POLICY CONCLUSIONS

On the basis of the available scientific literature and the research undertaken by the Commission's own services (in particular the results of the Community's JOULE programme, the preliminary results of an assessment prepared for the Commission's Cellule de Prospective by the Institute for Prospective Technological Studies of the Joint Research Centre and DG XVII's "Energy for a new century" exercise), economic analysis allows a number of conclusions to be drawn that are of significant importance when defining economically efficient response strategies in the context of global climate change. These conclusions concern both the appropriate methodology of approaching the problem and the main empirical findings.

1. Before presenting the economic conclusions, the general background has to be briefly sketched. It is generally recognized that a continuation of present trends in worldwide energy use would drastically increase worldwide CO_2 emissions: in the "business-as-usual" scenario prepared by the Intergovernmental Panel on Climate Change (IPCC), for example, worldwide CO_2 emissions are projected to increase by roughly 60% in only 20 years. It is considered to be certain that this would lead to a substantial increase in atmospheric concentrations of greenhouse gases, thereby enhancing the greenhouse effect and resulting, on average, in an additional warming of the earth's surface.

2. From the point of view of economic theory, the optimal way to define **policy targets** in this context would be by making a <u>comprehensive comparison of the costs and the benefits of different policy options</u>. This comparison would also have to take into account factors such as uncertainty, the rights of future generations and the dangers of irreversible damage to the environment. In principle, such a comprehensive cost-benefit analysis would make it possible to determine at the same time the quantity of the desirable emission reduction and the costs (or benefits) associated with such a reduction.

   However, it is highly doubtful whether the information available to date allows such a comprehensive and quantitative cost-benefit analysis to be made with any degree of reliability. In this situation, there are basically two approaches that may serve as a guideline for defining greenhouse gas policies:

   - the <u>"absorption approach"</u>, assuming that the earth's eco-system (and therefore also our economies) can only absorb a certain amount of global warming (in absolute terms or per decade). Some authors argue, for example, that the earth's eco-system could only manage a warming of not more than 0.1° per decade. Provided such a limit can be defined scientifically, policies would have to be designed so as to guarantee the corresponding <u>quantity</u> of emission reduction, theoretically without explicit analysis of the associated economic costs.

   - the <u>"insurance approach"</u>, arguing that, in the absence of reliable knowledge concerning the impacts of global warming, it would be rational to undertake not only all emission reduction measures that can at the same time be justified on other grounds ("no regrets policy"), but also that society invest in further measures just in order to reduce the risk of the worst case scenario occurring. Thus a certain amount of <u>financial resources</u> would be spent, theoretically more or less independently of the size of the resulting emission reduction.

3. Concerning the first approach (absorption), the crucial question is whether the absorptive capacity of the eco-system with respect to global warming can be quantified scientifically or not. If it can be specified, economic analysis is not required for defining quantitative emission reduction targets. Instead, the task of economic analysis becomes to identify the least-cost policy instrument setting to attain the scientifically defined reduction targets.

4. With respect to the second approach (insurance), the role of economic analysis is to evaluate and quantify the cost of reaching different emission reduction targets. The lower the aggregate costs of emission reduction, the higher the amount of emission reduction that can be reached with the amount of financial resources society is willing to spend.

5. Two alternative approaches are generally used for the economic evaluation of greenhouse gas emission reduction policies: the "bottom-up" analysis and the "top-down" analysis.

6. The "bottom-up" approach attempts to identify the costs of attaining different emission reduction targets by aggregating the microeconomic costs derived from a detailed analysis by technology and by economic sector. The aggregate emission reduction cost curve can then be used for deciding upon a possible quantitative emission reduction target.

7. The available empirical studies conducting a "bottom-up" analysis indicate the existence of a significant emission reduction potential, the exploitation of which would appear to offer clear (short-run) economic benefits. In fact, the exploitation of this emission reduction potential would in principle be profitable for private economic agents, even at current market prices. This potential is currently not exploited due to market failures, institutional barriers or hidden transaction costs. Examples of these different types of barriers are capital constraints, lack of information, discount rate differences, utility regulation, separation of expenditure and benefit of emission reduction investments, etc.. Moreover, uncertainty with respect to future energy price trends might often constitute a further "invisible barrier" to energy saving investments.

   In addition to this privately profitable emission reduction potential, there is a further potential that should be exploited from the point of view of society, but that is currently not used. Thus, if market prices were to fully reflect all social (i.e. including environmental) costs, the potential for (privately) rational emission reduction measures would be even larger.

   Concerning the available technological options for reducing CO_2 emissions, it appears that the improvement of energy efficiency represents the most important economically justified and immediately available potential for emission reductions, followed by fuel switching towards fossil fuels with low carbon content. In the longer run, renewable energy sources could represent an important CO_2 emission reduction potential and public R&D policy can help accelerate the economic viability of such technologies. Certain renewable energy technologies are already cost-effective if CO_2 emission reduction targets are to be attained.

8. As to the size of the potential for economical (from the point of view of society) or "nearly economical" emission reduction measures, the exact amount differs between countries and economic sectors. For the Community as a whole, it could tentatively be estimated to be at least of the order of 15-20% of "business-as-usual" energy related CO_2 emissions by the year 2010.

In sectoral terms, it appears that there is a large energy saving (and therefore emission reduction) potential in the residential and commercial sector (currently contributing approximately 24% to the Community's CO_2 emissions). In particular in the area of heating (space and water), potential energy efficiency gains of over 50% seem to exist. Other important cost-effective savings are associated with efficient lighting methods. There is also an important energy efficiency potential in industry (current share in emissions close to 20%), probably of the same order or maybe slightly smaller than the potential in the domestic sector. The main technological options consist of the combined on-site generation of heat and power (CHP) and improvements in space, water and process heat generation. While in the transport sector (current share in emissions roughly 23%), the potential for increasing energy efficiency (mainly by increasing engine efficiency and reducing the car body weight) is estimated to be high (economic potential possibly around 20%), past experience has shown the difficulty of attaining emission reductions in the area of road transport. In the power generation sector (the source of approximately 30% of present CO_2 emissions), finally, cogeneration (CHP) and advanced combustion technologies could increase conversion efficiencies by over 10 percentage points. In addition, emissions could be reduced by means of fuel switching.

9. Exploiting this existing economic emission reduction potential

- is in the economic interest of each country, provided policies are designed to be economically efficient. It is therefore a prime example of a policy that should be undertaken even when abstracting from the advantages of mitigating global warming ("no regrets policies");

- therefore usually requires no international agreement (although such an agreement could provide additional momentum), thus representing an immediately available first step in a long-term response strategy towards global climate change;

- will require significant efforts and policy changes. Without such efforts, the exploitation of this economic emission reduction potential would either be costly or altogether unattainable.

10. Although the technical potential appears to exist for reducing emissions by significantly more than currently appears economically viable (sometimes a figure for the overall reduction potential of the order of 40% is quoted), this additional amount of emission reduction may imply significant economic costs (neglecting, however, possible environmental benefits). These costs are likely to be markedly higher for isolated action compared to joint action.

The desirable amount of emission reduction beyond the economic break-even point of what is currently economically viable depends on the risk aversion of society (or policy-makers).

11. In comparison to the "bottom-up" approach, the "top-down" approach, takes a more aggregate, macroeconomic point of view. Starting from the observation that the actual quantity of CO_2 emissions exceeds what is considered to be the equilibrium amount, it concludes that the obvious way to reduce emissions is to increase the "price" of emissions. By raising the cost the individual economic agent has to bear when emitting CO_2, more emission reduction measures become profitable for the private sector.

One of the most appropriate policy instruments for achieving this are taxes. The economic justification for raising (or introducing) taxes on emissions or emission generating activities is the existence of externalities (social costs exceeding private costs), which are internalized into market prices by means of taxation. Theoretically, the size of the tax rate therefore depends on the size of the externalities. In the absence of a reliable, monetized estimate of these externalities, a more pragmatic procedure is normally used. In this case, the tax rate is simply determined on the basis of what is required to reach a given overall emission reduction target.

12. The existing empirical studies based on a "top-down" analysis generally come to the conclusion that, in the short-run, tax rates on CO_2 emissions or, alternatively, fossil fuel use have to be relatively high (tax rates in the range of 50%-150% of present energy prices are often quoted in the literature), if the aim is to attain emission reduction targets of, say, 20% (compared to a business-as-usual scenario) solely by relying on taxation. However, it is important to note that if energy price expectations were altered by a declared long-run progressive increase in taxation, then elasticities calculated from past behaviour could underestimate the possible demand response.

Most available studies also show that - for the amount of emission reduction currently under consideration politically - the macroeconomic effects of such taxation are likely to be relatively small or even absent, provided the tax revenues are recycled to the private sector (e.g. by introducing a revenue-neutral tax). For a 20% emission reduction (compared to the reference scenario), for example, a possible cost in terms of GDP loss of the order of 0.5-1.5% is usually found in the literature (i.e., when spread over a ten-year period, a possible reduction in the annual rate of GDP growth of between 0.05 and 0.15 percentage points). Although these effects are likely to increase progressively with the level of emission reduction, this is nevertheless an important result showing that controlling greenhouse gas emissions is not per se incompatible with economic growth.

It has to be emphasized, in this context, that these potential GDP losses should not be interpreted as the net costs of a CO_2 reduction policy (and therefore as the "insurance premium"). Instead, the broader environmental and other (non-market valued) benefits from a reduced combustion of fossil fuels have to be balanced against the economic costs of emission reduction measures before attempting any judgement on the likely welfare implications of a CO_2 reduction policy (e.g. reduced SO_2 and NO_X emissions and therefore reduced acid rain).

Despite these arguments, there are likely to be sectoral and distributional effects of considerable importance. In particular, the differentiated effects on different household income classes may have to be compensated by an appropriate redistribution of the tax revenues. Also, certain energy-intensive industrial branches could be significantly affected (adjustment costs), notably in the case of unilateral action. On the other hand, other branches can be expected to gain, at least in the medium to long term, from the timely response to global environmental threats ("first mover advantage"). Finally, there is an additional distributional aspect of importance in the context of the European Community: the distribution of the effects of emission reduction policies among Member States. In view of the differences in terms of the sectoral composition of output, the fuel mix, the climatic conditions etc., this distribution is likely to be unequal.

13. A comparison of the empirical results arrived at on the basis of the "bottom-up" and the "top-down" approach, respectively, may appear to give a somewhat conflicting message: On the one hand, a large and economically viable emission reduction potential and, on the other hand, high tax rates (associated with GDP losses)

required to reduce emissions significantly. Two arguments may help to reconcile this apparent contradiction: First, taxes have an important role to play, but on their own they are insufficient to exploit the full emission reduction potential. By definition, market-based instruments like taxes can only be economically efficient where markets exist and work efficiently. However, a microeconomic, "bottom-up" analysis illustrates the necessity of using a variety of instruments. Second, the existence of a large reduction potential does not by itself imply that it will be easy to exploit this potential. Thus, a technology-oriented bottom-up analysis is likely to underestimate the difficulties and the costs of exploiting the existing cost-effective emission reduction potential, thereby overestimating the achievable emission reduction.

14. In view of the above discussion, it becomes clear that economically efficient policies to exploit the CO_2 emission reduction potential should be a mix of traditional, in particular regulatory instruments and market-based instruments. In the Community context, this instrument mix also has to reconcile the desire for decentralized policies with that for a single market.

15. Traditional, in particular regulatory instruments of environmental policy have an important role to play in a comprehensive response strategy against the risk of global warming in particular as far as energy use in the residential sector is concerned. Most importantly, this could be in the form of regulations specifying maximum emission standards or minimum energy efficiency standards. On the other hand, voluntary agreements with producers have sometimes proved effective in the past. In addition, measures to improve energy consumers' information (e.g. by energy efficiency labelling and subsidisation of energy efficiency consulting) as well as other accompanying policies such as transport, industry, agriculture, research and development, training and education, etc. have a significant role to play.

16. From the point of view of static and dynamic efficiency, market-based instruments seem to be a particularly suitable component in a policy-mix aiming at a reduction in greenhouse gas, and in particular CO_2, emissions: there are no direct health hazards involved, the regional distribution of CO_2 emissions is of no importance for the climatic consequences and practically all economic agents are involved.

In particular, two classes of broad-based instruments using the market mechanism are of importance: fiscal instruments, on the one hand, and instruments to create new markets or improve the functioning of existing markets.

17. Fiscal instruments are likely to have a central role to play in any policy to reduce CO_2 emissions. By internalizing the social costs of fossil fuel use, private economic agents are encouraged to take into account the scarcity of natural resources (fossil fuels as well as atmosphere) when taking their decisions. They thus receive the correct signals.

Concerning the choice between different types of taxes, e.g. a carbon tax or an energy tax, the precise policy objective is of crucial importance. If the objective is to mitigate global warming, a carbon tax appears to be economically superior to a general energy tax. Moreover, a revenue neutral introduction of a carbon tax is likely to minimize the risk of possible adverse short-run economic effects. A general energy tax, on the other hand, is sometimes seen as having certain advantages in terms of broader environmental and/or energy policy objectives. Although economic analysis would suggest promoting these objectives by using other policy instruments in combination with a carbon tax, political considerations might lead to the conclusion that a general energy tax could constitute a "second best" solution.

The overall policy objective also determines the choice between taxes and charges (hypothecated taxes). In general, economic reasoning would argue against the earmarking of carbon/energy tax revenues as this would introduce undesirable budgetary rigidities. Moreover, if the political aim is not to raise the public sector's share in GDP, revenue neutral incentive taxes, introduced in the context of fiscal reform, seem to be the preferable solution. On the other hand, charges can be seen as having some political attractions. The fact of earmarking the revenues from a new tax for environmental purposes may, for example, make the introduction of such a new tax more acceptable to the electorate. Thus, a scheme of revenue-raising emission charges for financing emission reduction measures is sometimes considered as an attractive policy option, in particular if there are low-cost emission reduction options which will not be spontaneously exploited by private economic agents and which therefore might require some public funding. Nevertheless, it can be expected that the objective of dynamic economic efficiency is unlikely to be attained in such a case.

18. The correction of market failures and the creation of new markets can significantly contribute to the reduction of emissions at least cost. The policies pursued in the past have indeed shown that traditional policy instruments only allow a limited exploitation of the existing, economically viable energy saving and emission reduction potential. Thus, innovative policy approaches are required.

- In this respect, least-cost or integrated resource planning in the utility sector could play an important role. The underlying philosophy of this and related concepts is to encourage utilities to provide energy services instead of supplying simply energy. By reforming utility regulation such as to guarantee an appropriate rate of return on energy saving measures, utilities, in their least-cost strategy to meet the increased demand for energy services, would not only focus on expanding technical supply capacity, but would also exploit economical energy saving opportunities.

  Another concept, third party financing, would allow specialized private companies with the required capital and technical expertise to exploit the economic potential for energy conservation that is presently not used either due to market imperfections or due to institutional barriers.

  These and other comparable policy instruments could help to exploit an energy saving (and therefore emission reduction) potential that is difficult to exploit by relying only on traditional fiscal instruments. They necessitate, however, significant regulatory reforms and behavioural changes.

- A second class of market creation instruments consists of tradable emission rights or permits. The basic idea of tradable permits is to limit the overall amount of acceptable (CO_2) emissions. Each emitter receives the right (permit) to emit a certain amount of CO_2. The economic efficiency of tradable permits lies in the fact that each permit holder compares the costs of reducing emissions by an additional amount with the gains from selling his emission permit. Thus, the market would ensure that emissions are reduced where this is least costly. The permits could be allocated on the basis of past emissions, of indicators or by auctioning.

  Tradable permits are a particularly efficient instrument in cases where it is important to respect an overall emission target (tax rates would probably have to be adjusted in a trial-and-error process to exactly attain the target) and where the number of participants is not so large as to imply high transaction costs. Moreover, tradable permits are an almost ideal instrument for a decentralized policy approach based on the subsidiarity principle as they give each participant the freedom to decide on the precise measures to be taken in order to respect the allocated emission target. As such, tradable emission rights can be applied either at the international level (where the permit holders are countries) or at the national level (where the permit holders are individual economic agents). However, to date only few practical experiences have been made with tradable permit schemes in the Community. Moreover, in the present Community context, the creation of the internal market would nevertheless restrict the free choice of policy instruments for individual Member States. In addition, there are difficult issues of permit allocation and monitoring to be addressed.

19. Concerning the design of a comprehensive and economically optimal greenhouse policy, the main conclusions are the following:

- In view of the importance of uncertainty, a policy approach has to be adopted that is flexible enough to be adaptable whenever new information becomes available. This has been emphasised by the IPCC's Response Strategies Working Group.

- Early, gradual and predictable action reduces adjustment costs for the individual economic agent as well as for society as a whole. Early adjustment is not only likely to reduce the cost of adjustment, but can also offer significant market opportunities for those producers ahead of the trend. Gradual action implies that tax rates should initially be set at a level high enough to give a clear signal to market participants, but not so high as to lead to excessive adjustment costs. Tax or charge rates should then gradually increase with time in order to encourage continued emission reduction efforts. Predictable policies, finally, are economically more efficient as they reduce uncertainty and allow market participants to form stable expectations.

- There are likely to be significant gains from coordinated policies. Coordinated action avoids not only distortions in competitivity, but also inefficiencies due to an international incompatibility of policy instruments. They also allow economies of scale to be realized in the field of technology.

20. The more ambitious emission reduction targets are, the more can be gained economically from adopting a broad policy framework. Thus, policies should not only focus on energy related CO_2 emissions in the Community, but also on:

(a) Carbon "sinks": Forests play a crucial role in sequestering CO_2. The available information clearly indicates that there are cases in which halting deforestation or even promoting reforestation is less costly than particular measures to reduce fossil fuel combustion. Moreover, in view of the rich variety of species living in tropical rain forests, halting deforestation could be seen as one of the important "no regrets" strategies in the context of the greenhouse effect.

(b) Other greenhouse gases: There is undoubtedly a point beyond which the marginal cost of reducing CO_2 emissions exceeds the cost of reducing other greenhouse gas emissions (e.g. CFCs or methane from landfills) in order to attain the same result in terms of the influence on the earth's radiative (i.e. heat) balance.

(c) Worldwide emissions: The potential economic gains from reaching a broad international agreement are extremely high. Although precise quantitative figures are difficult to obtain, it is often estimated that the marginal cost of emission reductions can vary by a factor of even 5-10 between different countries (e.g. between Western and Eastern European countries).

21. The greenhouse effect is a global problem, which cannot be resolved by one or two countries alone. An international agreement is therefore an essential ingredient in any response strategy. However, reaching such an agreement will be difficult (in particular in view of the temptation to act as a "free rider") and will only be possible if each potential participant is convinced that he/she will receive (economic) gains from it. Two issues are of particular relevance in this context:

- Within the Community, a common policy approach must be elaborated that takes into account the cost differences of CO_2 reduction measures between Member States. Quantitative emission reduction targets that do not take these differences into account are economically inefficient. As a matter of fact, economic theory would lead to the conclusion that only a uniform (carbon or energy) tax or a scheme of tradable (emission) permits would ensure economic efficiency.

- At the worldwide level, participation of developing countries is of crucial importance. This is not to say that participation must be ensured before emission reduction measures are taken. On the contrary, the above analysis has shown the existence of an emission reduction potential which industrialized countries should already exploit, because this would be in their own interest. In addition, industrialized countries have not only the financial but also the technological resources required to fulfil this task. Moreover, they are largely responsible for the man-made increase in atmospheric concentrations of greenhouse gases.

  However, in the long-run, any greenhouse gas emission reduction strategy which does not include the participation of the main fossil fuel using developing countries is bound to fail. In view of the prevailing large-scale inefficiencies in the use of energy in most developing countries, some CO_2 emission limitation would clearly be in the short term economic interest of these countries themselves (even when abstracting from the advantages for the environment). However, should the risks of global climate change be confirmed, such "no regrets policies" will not be sufficient. It is therefore necessary to develop mechanisms for the transfer of financial resources and technology that allow LDCs to face their task.

By setting the example and showing that emission reduction is not in conflict with economic prosperity, the European Community, together with other OECD countries, could ensure the participation of countries like China, USSR or Brazil in a future agreement. In acting together, the Community would ensure that progress on the Internal Market is maintained and, in view of potential international market opportunities, the Community should strategically assess whether a first mover advantage exists.

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